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Reproduction, Rearing, and Management of Anadromous Fishes

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Culture Techniques for Atlantic Salmon In the Northeastern United States

by

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Abstract. Atlantic Salmon (*Salmo salar L.*) enter rivers in the northeastern United States from April through October. Adult salmon are trapped during their upriver migration and transported in tank trucks to fish hatcheries, where they are held until spawning.

Sea-run salmon are very susceptible to handling-induced fungal infection, and specially constructed fish tubes are used to remove fish from the traps and trucks. Transport water is well oxygenated and cooled with ice. Injections with antibiotic and vaccine are given to each fish if the holding facility has a history of bacterial pathogens.

Fungal infections in the hatcheries are controlled by treating the holding pools with 100–250 ppm formalin or 1–2 ppm malachite green. If malachite green is used, U.S. Food and Drug Administration regulations require the use of activated carbon filters to remove the malachite green from the treatment water before it is released into the environment. Fish tested with malachite green cannot be released or used as food fish.

Air spawning is used to strip eggs from females. Eggs are water hardened in 75–100 ppm iodophor for 1 h, enumerated volumetrically, and incubated in Heath incubators. Egg survival generally exceeds 85%. Water temperature is increased to shorten incubation time, thereby increasing the percentage of 1-year smolts that can be achieved in a single growing season.

Alevin are started on feed using semi-moist diets or brine shrimp. Survival 6 weeks after initial feeding normally exceeds 85%. When alevin are feeding strongly, they are switched to a specially formulated salmon diet high in protein and fat. The feed is dispersed to the alevin by automatic feeders. Parr are also fed the same salmon diet, and are fed from automatic feeders or demand feeders.

All water used in the rearing regime at salmon production hatcheries is treated with ultraviolet light unless the water supply is a spring or well source that is free of fish pathogens.

Fish that achieve smolt size by spring are pumped into distribution trucks at the hatcheries and transported to the river or smolt release facilities. Displacement gauges or manometers are used to estimate the weight and number of fish loaded onto each truck.

Outmigrating smolts leave the rivers in late April and early May and embark on a journey that takes them past Newfoundland and Labrador and into the Davis Straits along the west coast of Greenland. Most fish emigrating from United States waters return to their home rivers 2 years later.

Adult Atlantic salmon (*Salmo salar* L.) ascend rivers in New England throughout spring, summer, and fall. The highest percentage of the total run occurs in June and July. Salmon entering New England's most productive salmon river, the Penobscot in Maine, are predominantly two-sea-winters fish. In 1985, this fish had a mean fork length of 71 cm and a mean weight of 3.8 kg (Baum 1988).

Sea-run salmon that are to be used for broodstock are trapped on the rivers and transported in tank trucks to hatcheries, where they are held until the spawning season. Bright salmon entering traps are extremely sensitive to handling stress, and special precautions must be taken during the trapping and transport process. Black vinyl bags, rubber socks, or polyvinyl-chloride pipes are used to remove fish from the trap or truck. These devices provide a water cushion for the fish, and the dark environment and confined space calm the fish and reduce thrashing, which often causes scale loss and mechanical injury.

Water used in transport tanks must be well oxygenated. Bottled oxygen dispensed through air stones or micropore tubing and used in combination with aerators or recirculating pumps maintains oxygen levels at or near saturation. Ice or refrigerated units are used to keep transport water below 18°C and to temper water when water temperature at the trap exceeds that at the holding facility by 6°C (Gaston 1988). Fish loading densities in transport tanks are kept below 0.6 kg per liter of water; travel time from the trap to the holding facility is 2 hours or less.

Control of Fish Diseases

Fish diseases are a major concern when adult salmon arrive at the hatchery holding facility. In the northeastern United States, *Aeromonas salmonicida* (furunculosis), *Yersinia ruckeri* (enteric redmouth disease), *Saprolegnia* sp. (fungus), and *Ichthyophthirius multifilis* (ich) have presented the most persistent disease control problems. For each of these pathogens, fish health protocols have been established to greatly reduce the extent of their impact.

Federal hatcheries in the northeastern United States under a program of disinfection and installation of water decontamination units, such as microsieve filtration and ultraviolet light, have been able to rear Atlantic salmon smolts and maintain captive broodstock that are largely free of *A. salmonicida* and *Y. ruckeri*. However, moderate numbers of returning sea-run broodfish are typically infected with these pathogens. Control of furunculosis and enteric redmouth disease in sea-run broodfish has been affected (under research permits) by intraperitoneal combination injections at capture with the bactericide oxolinic acid (at 2.4 mg/kg fish) and the dual vaccine of *A. salmonicida* and *Y. ruckeri* (at 0.5 mL/kg fish up to 2.5 mL), with good results. Broodfish that are held for an additional year or more such as in a kelt reconditioning program, receive an annual booster of the vaccine.

Several approaches have been used for control of *Saprolegnia* sp. Of these, the method of choice is that of careful handling procedures at capture, which prevents injuries that would allow the pathogen to become established. Once the fish has become infested, however, the most effective treatment has been 2 ppm baths of malachite green. A major drawback to this treatment is that malachite green has been recognized as a possible teratogenic agent. Therefore, use of the chemical is tightly controlled: all treated water is filtered through activated charcoal filters and fish no longer needed for production are incinerated. A third method of fungus control which has been employed during the past several years with good results is the routine use of prophylactic fomalin treatments of 250 ppm every 1–3 days. This treatment is not effective if the fungus is established on the fish.

The parasite *Ichthyopthirius* sp., because of its extended life cycle, often presents control problems not encountered with other protozan parasites. Formalin remains the treatment of choice at either 25 ppm indefinitely or 100–250 ppm in 60-min flow-through. An experimental vaccine developed from *Tetrahymena* sp. at the National Fishery Center (Leetown) is scheduled for testing this spring.

Future fish health work in the northern United States will focus on reducing or preventing the occurrence of the most serious fish pathogens. In this regard, the progress in vaccine development for viral pathogens and *Renibacterium salmoninarum* has been limited. Development of vaccines for *Vibrio* sp., *A salmonicida*, and *Y. ruckeri*, however, has progressed satisfactorily.

Although *Vibrio* sp. does not seem to cause major problems in the Atlantic salmon restoration program, vibriosis certainly has and does create problems for the aquaculture industry. Fortunately, the immersion vaccines for *Vibrio* sp. are very effective.

The immersion vaccines for *Y. ruckeri* have been employed for a number of years in private as well as government hatcheries and have worked well. And the production of an effective immersion vaccine against *A. salmonicida* has progressed beyond the experimental stage and has undergone trials in Canada where it is now licensed. The results of these tests have been outstanding enough in the control of furunculosis to create an order of approximately 10,000 L of vaccine for aquaculture in the United Kingdom.

Pathogens currently outside the scope of control by vaccines will continue to rely upon management strategies and treatment control measures. Research for licensing fish medications has placed high priority on a replacement fungicide for malachite green and registration of the chemical Chloramine T for control of bacterial gill disease.

After the broodstock arrive at the hatchery, they can be held in various types of holding pools including Swedish pools, circular pools, raceways, and earthen ponds. Pools should be covered and have a freeboard of 180 cm or more above the water surface to prevent fish from jumping out. Water alarms and intrusion alarms should be standard parts of the holding facilities.

Water flows should be high enough to maintain oxygen levels at saturation and should be injected into the holding ponds at an angle to create a current. A spray bar is ideal for creating a current in Swedish or circular pools. The angle of injection can be adjusted to increase or decrease water velocity.

The number of adult salmon that can be held in a pool will depend on the holding area and available water flow but is also affected by temperature, cover, and many other factors. At the Craig Brook (Maine) National Fish Hatchery, up to 230 fish, weighing 5 kg each, have been held successfully in a 120-m^2 Swedish pool with a water depth of 60 cm, a maximum water temperature of 17°C during the warmest months, and a water flow of 400 L/min (100 gpm). The relatively low water inflow rate was acceptable because Atlantic salmon do not feed after they enter fresh water.

Atlantic salmon are usually held 3–6 months before they mature sexually. During holding, most salmon culturists think that broodfish should be kept in water temperatures averaging 13–16°C. Fluctuations ranging from 10–21°C are tolerable and not uncommon.

Water for salmon broodstock should be taken from a disease-free source, such as a well or protected spring: otherwise, the water supply should be filtered and treated with ultraviolet light. Even if the water supply is disease free, wild salmon often carry parasites and pathogenic bacteria that can cause serious losses. Culturists must be alert for any unusual behavior exhibited by the fish, which may indicate a disease problem. Increased jumping (crashing) by the fish in the brood pools, unexplained repositioning in the water column, or increased gaping are signs of disease. Fish should be examined immediately and treated if a pathogen is discovered. As a matter of routine, all dead broodstock should be necropsied to determine the cause of death. Minimum requirements during the autopsy are kidney and gut slants, kidney smears, parasite check of body and gills, and a general examination of the internal and external condition of the fish, during which any tears, bruises, internal bleeding, or hemorrhagic areas are noted.

Spawning Operations

Spawning of Atlantic salmon usually begins in late October and continues through November. The spawning operation begins with sectioning the spawning facility or holding pool to segregate fish into five groups: males, ripe females, unripe females, barren fish, and spent fish. The sexing and sorting operation should minimize fish handling.

After sex is determined, males and females are separated 10–14 days before the anticipated date of ripening of the earliest maturing fish. Maturation is regulated by day length and water temperature, unless hormones are used. Check females for ripeness at 5–7-day intervals, or more often if they are close to spawning.

Eggs are taken from ripe females and fertilized using the following procedures (Hendrix 1989):

1. The "dry method" of spawning (absence of water) is the recommended procedure for Atlantic salmon. The spawning pan should be dark, smooth, and made of plastic or porcelain. The dark color helps spawn takers to see broken or inferior eggs. When a problem with the eggs is detected, the stream of undesirable eggs should be diverted into a separate pan and discarded. If

air and water temperatures differ by more than a few degrees, steps should be taken to avoid temperature shock.

2. At the beginning of the spawning season, milt from several males should be examined microscopically for sperm viability. The milt is prepared by mixing it with saline or ovarian fluid on a microscope slide and immediately checking for sperm motility and abnormal structure. Samples should be rechecked if poor viability is suspected. Current practice is to use milt from one male to fertilize one female. For genetic considerations, only single-pair matings should be made when progeny will be kept for broodstock. The number of males and females used in each spawning set should always be equal to provide a 1:1 sex ratio.

   Milt can be taken the day before the eggs are collected if it is properly stored and refrigerated to maintain sperm viability. One method of storing or transporting sperm (suggested by Ray Simon, National Fish Health Research Laboratory) is to place about 3 mL of milt in small, thin, plastic bags (sandwich or freezer bags), seal the top, and place the bags on ice in a container filled with oxygen. The oxygen diffuses through the plastic bags and sustains sperm life. At Craig Brook National Fish Hatchery, milt collected in test tubes and held on ice remained viable for at least 12 h.

   Males are either anesthetized or put in a flopping net and allowed to tire before milt is taken. When milt is being collected, care must be taken to prevent water contamination or the milt will be rendered useless.

   Eggs can be fertilized by milt applied directly from the male fish, but precollection saves time during the busy spawning operation.

3. Four or five females are netted, preferably one fish at a time if the fish are large, and placed into a tub of water containing 100–150 ppm of the anesthetic tricaine methanesulfonate (MS-222). Assign one member of the spawning team to add females to the anesthetic container so that the spawning operation is not delayed, and to monitor exposure time to avoid overexposure and death.

4. After the fish are anesthetized, record the desired information: length, weight, and tag number of marks. The anesthetized fish, as well as gloves or hands that come into contact with MS-222, are rinsed in clean water before actual spawning to prevent anesthetic contamination of the eggs.

5 Air spawning is used at most hatcheries to extract eggs from ripe females. With this procedure, an air gun is fitted with a 1.27-cm-long, 18-gauge needle, and air is injected at the base of the pelvic fin directly into the body cavity of the fish, forcing eggs out of the genital opening. An air compressor or cylinder, controlled by regulators set at low line pressure (4–8 L/min), provides a constant air supply to the gun. This method requires two people but is fast, clean, and less tiring than hand spawning.

   Nets to catch eggs during extrusion, or the addition of 0.9% saline, have improved egg eye-up percentage of Atlantic salmon kelts and domesticated trout but not of sea-run Atlantic salmon at Craig Brook National Fish Hatchery.

6. During stripping, every precaution should be taken to prevent water, slime, or other debris from entering the spawning pan. Hold the female so that the opening is over, but not touching, the edge of the pan. Be especially careful to prevent water and slime from running down the anal fin., the fish's body, or the spawn taker's glove and into the spawning pan.

7. Eggs and milt are then mixed. Milt is added to the eggs either from stored sperm or directly from the male and gently mixed by using a clean hand, soft spatula, or brush. Because sperm remains active longer in ovarian fluid than in water, it is not recommended that water be added to the egg-milt mixture. Mixing of eggs and milt should be completed immediately after the milt is added to the eggs because activated sperm survives only 15–30 s.

8. After fertilization is complete, the eggs are washed with clean water, which is then poured off to remove excess milt, debris, bad eggs, and egg shells. The eggs are then water hardened in an iodophor solution (75–100 ppm iodophor) for 1 hr. If the iodophor is not already buffered, it is buffered with bicarbonate of soda until the pH of the solution approximates the pH of the water in which the eggs are held. After disinfection, eggs are measured volumetrically and allocated to incubation units. At Craig Brook National Fish Hatchery, treatment of eyed eggs with 100 ppm

iodophor was limited to no more than 10 min because longer treatment caused premature hatching and mortality. The exposure time for green eggs is less critical, even when they are treated during water-hardening.

9. Eggs should never be exposed to direct sunlight, and exposure to indirect sunlight should be minimized. The spawning pool should be provided with a shelter to protect eggs from direct sunlight, precipitation, and extreme temperature fluctuations. A shelter also provides a warmer and drier place for the spawn takers to work.

Captive Broodstocks

Captive broodstock are also used as an Atlantic salmon egg source. Captive stock are progeny from wild, sea-run Atlantic salmon that have been reared to sexual maturity in a hatchery. Progeny from captive broodstocks are considered to be domesticated; therefore, they are not recommended as broodstock. Rather, all progeny of captive broodstock are stocked as fry, parr, or smolts.

Fish are chosen for a captive broodstock by random selection from a large group of pre-smolts. The selected fish may be transferred directly into brood pools or remain in rearing pools through late spring and summer before being moved in fall. Brood pools are raceways, circular pools, Swedish pools, earthen ponds, or square pools that are covered or indoors to reduce light intensity. Pool sides must extend 180 cm or more above the water surface to prevent fish from jumping out. Eggs taken from fish held at densities reaching 35 kg of fish per cubic meter (2.3 lb per cubic foot) had no significant reduction in hatchability compared with eggs taken from fish held at lower densities.

Captive broodstocks should be held in high quality water. At the Green Lake (Maine) National Fish Hatchery, broodstocks produce high quality eggs at temperatures of 0.5–3°C in winter and 18–19°C in summer. Water temperatures vary with natural fluctuations in the lake water supply, and water flows are set so that oxygen levels remain at or near saturation. Water depth in rearing tanks is usually 90 cm but may vary from 45 to 180 cm.

Artificial diets are readily taken by captive broodstock. The open-formula ASD2-30 diet has been especially effective, providing excellent growth, feed conversion, and egg quality. Broodfish are fed to satiation using automatic feeders, demand feeders, or hand feeding. Feeding activity is reduced as water temperatures decline, but fish continue to feed even during winter.

Captive broodstocks usually reach sexual maturity at 4 years, although a few may produce gametes at 3 years. The quality of eggs from first-time spawners is considerably better than that of eggs from fish spawning for a second or third time. For this reason, only first-time spawners should be used as broodstock. A broodstock operation in which only first-time spawners are used provides higher quality eggs and savings in space, labor, and fish food.

Kelts provided another egg source. "Kelt" is the name given to sea-run salmon after they spawn. Kelts can be held in fresh water and rejuvenated for repeat spawning after 1 or 2 years. At the Berkshire (Massachusetts) Trout Hatchery, kelts are vaccinated for enteric redmouth disease and furunculosis 2–3 weeks prior to receipt and are placed in small fiberglass tanks containing about 60 cm of water. Water temperatures of 3–7° are adequate for kelt rejuvenation at the Berkshire facility, but higher temperatures may be better. Water flows are set to maintain oxygen near saturation levels.

Resumption of feeding is the most critical hurdle to overcome in kelt rejuvenation. Kelts are held undisturbed for a week after they arrive at the station before initial feeding is attempted. A food ball attached to the end of the stiff wire is made from a combination of ingredients, including herring and shrimp paste, liver, ASD2-30 starter, and vitamin and mineral supplements. Some fish take the food immediately, others require periods of coaxing. After fish take the first food, they are enticed to take food dropped in front of them, and then food thrown directly into the holding pool. Within 1 month, most fish are feeding aggressively and can be fed to satiation. When fish are feeding normally, they are moved to 6.7 m in diameter circular pools, where feeding continues until the spawning season. About 25 fish are held in each pool.

Fungicides and 1.5% salt solutions should be used on an as-needed basis to control fungus infection. Egg quality declines with kelt age, in a pattern similar to that in captive stock.

Incubation

After spawning, Atlantic salmon eggs are incubated in Heath incubators, jars, or troughs, with Heath incubators being the most commonly used. A 16-tray Heath unit can successfully incubate 150,000 eggs to eye-up using a water flow of 14–15 L/min. Eggs should always be incubated in darkness because rays from artificial lights can reduce growth and cause liver damage. Substrate made of plastic products and placed in incubation trays has proven to increase size of fry. Care should be exercised, however, not to incorporate substrate so elaborate as to hamper proper care of the fry.

Atlantic salmon eggs have been incubated successfully at water temperatures ranging from 1 to 9°C. Temperatures above 9°C are not recommended and can cause premature hatch and increased mortality. Heat exchangers, spring water, or heat pumps are used at most salmon hatcheries to elevate incubating temperatures above ambient to hasten development. By shortening incubating time on eggs and fry, additional grown time is gained during a production season, and more smolts can be produced in 1 year rather than requiring 2 years. It is best to elevate water temperatures after hatching, increasing temperatures slowly at first. Table 1 may be used as a guide to predict important events that occur during egg and fry development.

Table 1. Daily percent development to initial feeding for Atlantic salmon[a]

[Values outside of the observed temperature range (3.8–8.0°C) are provided for completeness. Accumulate percent development daily based on the mean daily water temperature. For example, 2 days at 2.2°C would equal 0.366 + 0.732 percent development.]

°C	+0.0	0.2	0.4	0.6	0.8
1	0.296	0.307	0.318	0.330	0.341
2	0.353	0.366	0.379	0.392	0.405
3	0.419	0.433	0.448	0.463	0.479
4	0.495	0.511	0.528	0.545	0.563
5	0.581	0.599	0.618	0.638	0.658
6	0.679	0.700	0.721	0.743	0.766
7	0.789	0.813	0.837	0.862	0.888
8	0.914	0.940	0.968	0.995	1.024
9	1.053	1.083	1.113	1.144	1.176
10	1.209	1.242	1.275	1.310	1.345
11	1.381	1.418	1.455	1.493	1.532
12	1.572	1.613	1.654	1.696	1.739

Milestones	
Embryonic stage	Cumulative percent development
Weakly eyed	29%
Strongly eyed	47%
90%hatched	58%
First feeding	100%

[a]Taken from Gaston (1988) Appendix D.

Feeding and Rearing

Fry are usually removed from incubation units just before yolk-sac absorption is complete. They are placed in rectangular troughs or tanks or circular fiberglass tanks, where initial feeding begins.

Atlantic salmon fry require a minimum water temperature of 10°C to start feeding well, but temperatures of 12–15°C are best. Moist and semimoist artificial diets, brine shrimp, and liver mixed with dry diets have all been used to start salmon feeding, and survival rate normally exceeds 85%. Survival has not been good where dry diets alone have been used.

Young salmon should be fed at frequent intervals. Revolving disk feeders used at Craig Brook National Fish Hatchery automatically and continually trickle small amounts of feed to the fish over a preset period (usually 16 h). Many other types of automatic feeders are used, with feeding intervals varying from hatchery to hatchery, but 1 h is the maximum time that should be permitted between feedings.

Once the fry are feeding well, they can be switched to a dry diet. The ASD2-30 diet (Table 2) is used throughout the rearing regime at salmon hatcheries in the northeastern United States. It is a high protein, high fat diet that has provided excellent growth and feed conversion.

When the fish have outgrown their nursery tanks, they are moved to outside rearing units. Atlantic salmon parr and smolts have been successfully reared in concrete raceways, earthen ponds, concrete or fiberglass circular pools, and square Swedish pools. Circular pools are preferred by most culturists because they provide high water velocity and promote self cleaning.

Any rearing unit that is used, other than a deep earthen pond, must be covered in some manner because direct sunlight affects the growth and health of salmon. Covers should be constructed so that they provide a natural photoperiod and uniform shade. Loading densities in the various rearing units depend on the size of fish and, because physical plants and water supplies differ, vary from hatchery to hatchery. Gaston (1988) calculated loading densities by using the formula

$$FI = \frac{\text{weight in pounds}}{\text{length in inches X flow in gallons per minute}},$$

where FI is flow index. Flow index relates weight in a particular rearing unit to the size of the fish and the water flow available. Flow index is only used to approximate loading densities and does not consider water temperature. Maximum flow indexes between 2 and 3 have been achieved in serial raceways and single-use ponds, but flow indexes of 1.5 or less are recommended. Feeding is done by automatic or demand feeders.

Nitrogen Supersaturation and Fish Pathogens

When providing water to Atlantic salmon, no matter which life state is being cultured, nitrogen supersaturation and fish pathogens must be considered. Nitrogen supersaturation is especially deadly to small fry. Packed columns, vacuum, degassers, and stripping with oxygen are methods currently used to control supersaturation. The problem is most likely to occur where deep wells are used as a water source.

Ultraviolet light is used to control bacterial, viral, and parasitic diseases at Federal Atlantic salmon hatcheries in New England. One large UV system is in place at Green Lake National Fish Hatchery. It is housed in a 18.3- X 24.4-m Armco insulated building. Water enters the building by gravity feed through 76- and 50.8-cm pipes, and is directed into three Passavant rotary microsieve filters, each of which has a 22,710 L/min capacity. One filter is always held in reserve on a rotating basis, ready to operate when one of the two filters in use breaks down or needs servicing. The units are larger than they appear to be: each rotating drum is 458 cm long by 305 cm in diameter. The filters operate on demand and are controlled by water level differential. The drums remain stationary until the 10- X 20-micron media starts to clog. When a preset differential between inflow and outflow levels is reached, the drums turn at either low or high speed—depending on the degree of clogging—for a preset length of time. If the differential has been corrected at the end of a preset washing period, the drums stop rotating, but filtration continues while the drums are stationary. Whenever the drums are turning, the media panels are being backwashed by filtered water under pressure. Each drum consists of 48 baskets covered with filter cloth. The cloth is manufactured in Germany, and replacement of each basket, usually required every 2 years, costs about $60.

Table 2. Formulation specifications for Atlantic salmon diet, ASDA-30

Fish food shall be composed of the following items. The final product shall carry the following guaranteed analysis:

Crude protein, not less than 58%
Herring meal protein, not less than 33%
Crude fat, not less than 17%
Moisture, not more than 10.0% at sack-off

Herring meal:	Minimum protein 67.5%, minimum fat 8%, maximum moisture 10%, maximum moisture 10%, maximum salt 5%, stored at manufacturer's plant no longer than 6 months as indicated by Bill of Lading. Pepsin digestibility not less than 92.5%. Different meals may not be combined for use in the feed.	[a]50
Dried shrimp meal:	Minimum protein 38%	5.0
Soy flour:	Defatted, minimum protein 48.5%, maximum fat 1% (flour must be adequately toasted with a protein dispersibility index 20).	[a]20.3
Dried blood flour only in granules No. 1 - No. 4.		10
Dried blood flour or ring dried blood meal in pellets, minimum protein 80%		
Trace mineral premix No. 2		1 lb per ton
Vitamin premix No. 30		
Granules		24 lbs per ton
Pellets		16 lbs per ton
Choline chloride, 50%		9 lbs per ton
Absorbic acid		3 lbs per ton
Herring oil:	Stabilized with 0.4% BHA-BHT (l:1) or 0.1% ethoxyquin, less than 3% free fatty acids, and must meet standards for peroxide (<10 meq/kg) and TBA value (<70 ppm)	[a]12
Lingnin sulfonate-pellet binder (e.g., Amberbon, Orzan, or equivalent)		1

[a]Herring meal may be increased depending upon protein content but must provide not less than 33% fish protein. Quantity of added oil may be adjusted so that the finished feed shall contain not less than 17% crude fat. Soy flour is to be adjusted to compensate for the above variations. Not less than 6% of the total fat shall be sprayed on the granules as a top dressing, the rest to be included in the feed mix.

Table 2. Formulation specifications for Atlantic salmon diet, ASDA-30--Continued.

Vitamin	Guaranteed potency (per pound of premix)
D calcium pantothenate	12.0 g
Pyridoxine (pyridoxine HC1)	3.5 g
Riboflavin	6.0 g
Niacinamide	25.0 g
Folic acid	1.0 g
Thiamine (thiamin monoitrate)	4.0 g
Biotin	40.0 g
Vitamin B.	2.5 g
Menadione sodium bisulfite complex	1.25 g
Vitamin E (d or d1 alpha tocopherol acetate)	40,000 i.u.
Vitamin D, stabilized	50,000 i.u.
Vitamin A (vitamin A palmitate or acetate) stabilized	750,000 USP

Choline chloride, ascorbic acid, and the vitamin premix No. 30 are to be stored separately and never mixed with another before being added to the feed mixture.

The certified vitamin premix is to be supplied by a recognized manufacturer and must show the date of preparation. The vitamin premix to be used is not to be held in storage longer than 4 months after date of premix preparation.

The vitamin premix is to be made with a wheat or soybean by-product base. Rice hulls or oat feed are not acceptable.

SPECIFICATION FOR TRACE MINERAL PREMIX NO. 2.

Mineral	Guaranteed analysis of element
Zinc (SnSO4 - 84 g/lb of mineral mix)	34.00 g/lb premix
Manganese (MnSO4 - 25 g/lb of mineral mix)	9.10 g/lb premix
Copper (CuSO4) - 1.75 g/lb of mineral mix)	0.70 g/lb premix
Potassium (K10 - 0.38 g/lb of mineral mix)	0.23 g/lb premix

An inert carrier can be used to make up the mixture to the pound.

From the filter tanks, the water passes through a manifold to UV sterilization chambers. There are five UV units, each rated for 11,355 L/min. Each unit has three banks of lights that can be operated independently (i.e., the unit can be operated with one-third, two-thirds, or all of the lights on). Operation of the UV chambers depends on the flow required and the dosage being applied; however, normal operating procedure calls for one or more complete units in reserve in case of trouble. As with the filters, use of the sterilizers is rotated. The sterilizers are equipped with an in-place cleaning system that utilizes a mild phosphoric acid as the cleaning agent. While all five sterilizers can be cleaned by the acid solution by two people in 1.5 d, it is necessary to hand clean the quartz sleeves surrounding the UV tubes at least once a year. This is a very time-consuming process. The UV sterilizers contain 1,320 tubes, each costing about $25 to replace. It is necessary to replace about one-third of the tubes each year. Electrical use for the entire system is about 75,000 kwh per month, and total operational and maintenance cost of the entire treatment plant, including station labor, is nearly $80,000 annually.

Water exists the sterilizer in 76- and 50.8-cm manifold pipes. Flow rates, temperature, and oxygen levels can be monitored, and the entire treatment plant is protected from power outages by a 250-kw standby generator. Treated water flows to the hatchery building, which houses the incubator room, the rearing room, the advanced rearing room, and the broodstock holding area. Water is also directed to the main smolt rearing area containing 102 circular pools that are 6.1 to 9.2 m in diameter.

Distribution of Smolts

Distribution of Atlantic salmon smolts begins in mid-April and continues through mid-May. Fish are loaded on large tank trucks by fish pumps and transported directly to the rivers. Because of the large number of fish involved, the sensitivity of the fish to net handling, and the high level of labor required during loading, a manometer system was developed at Craig Brook National Fish Hatchery that eliminates net handling of smolts and provides an extremely accurate measure of the number of fish being loaded.

The system uses a Dwyer No. 246 inclined manometer to convert pressure charge into inches of water displaced. Vinyl or tygon plastic tubing (0.64 cm) is connected to one end of the manometer, and the other end of the tubing is fastened, for stability, inside a short piece of 1.9-cm PVC pipe. The end of the manometer opposite the tube connection is vented to the atmosphere. The pipe containing the tube is inserted into the tank water to a depth of about 2.5 cm, and held in place with a clamp. About 45.7 cm from the manometer, a T is inserted into the 0.64- cm tubing. A second piece of 0.64-cm tubing is used to connect the T to a Dwyer VFA-2-BV flow meter. The flow meter is connected directly to a Conoflow GH21XTXM constant differential pressure regulator. A third piece of 0.64-cm tubing connects the regulator to a small air compressor. The air compressor should be capable of delivering a minimum of 10 pounds per square inch (psi), but no more than 100 psi of pressure, and can be powered by alternating (AC) or direct (DC) current. The system works by sensing the hydrostatic pressure change that occurs when water in the tank is displaced by fish and rises. The manometer scale reads the pressure change as inches of water (conversion is built into the scale). A regression line is then drawn that relates weight of fish to inches of water displaced. This is done by loading known weights of fish into a distribution tank and taking readings from the manometer before and after loading. The difference in the two figures is the amount of water displaced. After an accurate regression line is dawn for each size tank used during distribution, fish need only be sample counted prior to loading. Fish pumping is stopped when the desired weight (as related to water displaced) is achieved. Number of fish is determined by multiplying the sample count by the total weight. A special oil (0.826 specific gravity) that expands the scale and makes reading easier and more precise is used in the manometer. The manometer can be read to 0.02 inches (0.05 cm). The purpose of the compressor is to provide air to the regulator. The regulator maintains a constant differential pressure between the flow meter inlet and outlet, and the flow meter enables the user to adjust the air bubbles that are being fed into the plastic tubing. The flow meter also provides a visual means of checking to ensure air is flowing to the system. The air bubbles purge the tubing of all liquid, which maintains the water level at the end of the tube. As the fish are loaded, the manometer then reads the change in hydrostatic pressure within the tube as the water level increases. Two things must be done to ensure accuracy. First, the manometer must be level. The Model

246 is made to be attached to a board, and it has a built-in leveling bubble and leveling adjustment. Second, the dewatering mechanism of the fish pump must be working properly. Any appreciable amount of water entering the fish tank during loading will affect accuracy and should be prevented or taken into consideration when figuring total weight loaded. Measuring fish by displacement is not new, but the manometer is far more accurate than the simple one-to-one sight gauges now in use, especially for large tanks where water level rises very little.

After loading, salmon smolts are trucked to the rivers. Loading rates in the transport tanks are about 0.12 kg of smolts per liter. Salt (NaCl) at 0.5% to 1.0% is added to the tanks to relieve stress. Once at the stocking site, quick release systems are used to flush the smolts through flexible tubing and into the river.

Outmigrating smolts leave the rivers in late April and early May and embark on a journey that takes them past Newfoundland, Labrador, and into the Davis Straits alng the west coast of Greenland (see Figure). Most fish emigrating from U.S. waters return to their home rivers 2 years later.

Conclusion

The Atlantic Salmon Restoration Program in the northeastern United States has produced encouraging results. In the 1960's the numbers of returning adult salmon were counted by tens; today we count by thousands. By gaining new knowledge, partly through information exchanges such as this Second U.S. - U.S.S.R. Symposium, there is hope that this magnificent fish can be fully restored to the waters of the United States.

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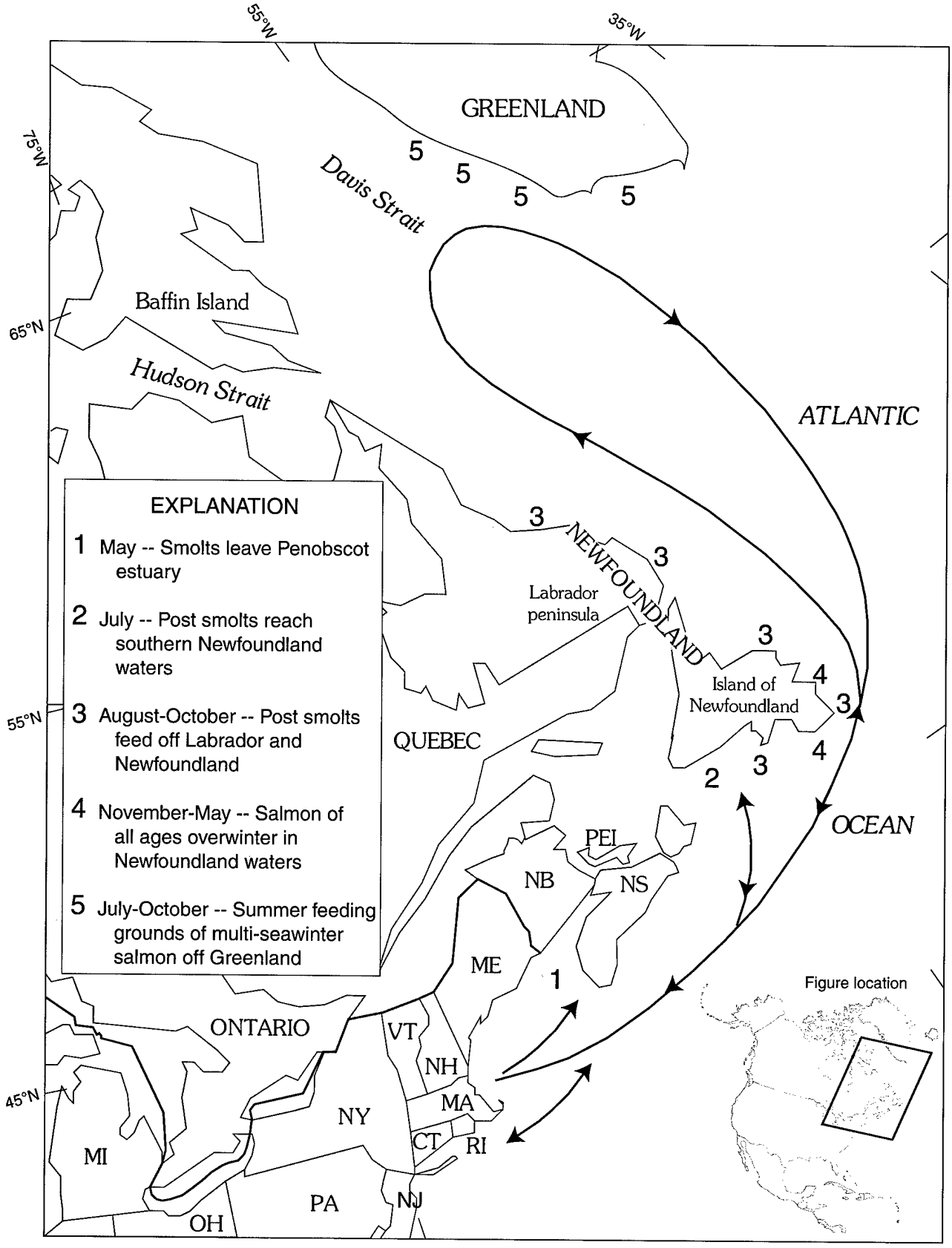

Figure 1. Migration route of Atlantic salmon in northwestern Atlantic Ocean (from Gaston 1988, Appendix A).

Induced Spawning of Atlantic Salmon In Marine Net-pens

by

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Abstract. Maturing 4- or 5-year old female Atlantic salmon (*Salmo salar* L.) were divided into groups of 10 to 20 fish and were tagged individually. The groups were placed in net-pens in either seawater (27 ppt) or net-pens in which there was brackish water (17 ppt) in the surface meter. Other groups were transferred to freshwater within 3 weeks before the normal peak-spawning time (November 1). Fish were injected intraperitoneally twice (3 days apart) with either 0.9% NaCl or a synthetic analogue of luteinizing hormone-releasing hormone (D-Ala^6, Pro^9-NEt LHRH; GnRHa) at doses of 2, 10, 20, or 25 μg/kg body weight. After ovulation, eggs from individual fish were fertilized and incubated in freshwater through hatching. These studies were conducted during 1983, 1984, and 1985.

All tested doses of GnRHa were effective in advancing and synchronizing spawning of fish regardless of environmental salinity. Of the saline-injected (control) fish, the proportion of spawning females was 100% in freshwater, 50% where there was access to brackish water, and zero in seawater. Most of the hormone-injected fish ovulated within 6 to 14 days after the first of the two injections. The survival to hatching for eggs and embryos from the hormone-injected fish in seawater or brackish water averaged zero (seawater and brackish water) in 1983, 45% (seawater) and 88% (brackish water) in 1984, and 75% (brackish water). These data indicate that fish held in seawater or brackish water must be checked frequently for ovulation to retain high rates of fertilization and embryo survival.

Injection of the brain hormone analogue, GnRHa, facilitates spawning of salmon in seawater or brackish water environments. Acceptable rates of egg fertilization and embryo survival may be realized if females are checked daily for ovulation.

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The brain peptide, gonadotrophin releasing hormone (GnRH), and its potent synthetic analogues stimulate the release of pituitary gonadotroin in all vertebrate classes (Peter et al. 1987). These peptides have been used successfully to induce spawning in a wide variety of teleosts (reviewed by Crim et al. 1987). In salmonids, GnRH has been used either alone or in combination with pituitary gonadotropin to advance or synchronize spawning of coho salmon (*Oncorhynchus kisutch*; Donaldson et al. 1981; Sower et al. 1982, 1984; Fitzpatrick et al. 1984, 1987) rainbow trout. (*O. mykiss*; Crim et al. 1983b, 1988; Sower et al. 1984) and Atlantic salmon (*Salmo salar* L.; Crim and Glebe, 1984; Crim et al. 1983a, 1986).

Interest in the use of the potent synthetic analogues of GnRH in spawning fish in public hatcheries or commercial aquaculture has been increasing because of the techniques's effectiveness and low cost. Furthermore, because GnRH analogues may be synthesized in the laboratory, their potency in inducing spawning is usually more consistent than preparations of pituitary gonadotropin isolated from natural sources. In the net-pen culture of Pacific salmon and Atlantic salmon in seawater, maturing adults are usually transferred to freshwater before the time of spawning because the fish do not spawn naturally in seawater and spawning in seawater is associated with reduced viability of the eggs (Clarke et al. 1977; Sower et al. 1982; Wertheimer 1984). However, the transfer of adult broodstock from seawater to freshwater increases stress of handling and cost and invites additional risk from such freshwater diseases as furunculosis and saprolegniasis. The potential of successfully spawning fish in seawater or brackish water is supported by anecdotal reports by fish farmers and observations that some oncorhynchids spawn successfully in the intertidal region (Helle 1979). The purpose of this study was to compare the effectiveness of D-Ala^6-Pro^9-NEt-ethylamide-luteinizing hormone-releasing hormone (GnRha) for inducing spawning and providing viable gametes from Atlantic salmon maintained in freshwater, in seawater net-pens, or in seawater net-pens with a brackish surface layer.

Materials and Methods

Experimental Animals and Facilities

Atlantic salmon were obtained as eyed eggs (certified disease-free) and reared in freshwater at the Northwest Fisheries Center, National Marine Fisheries Service (NMFS), Seattle, Wash., or at Big Beef Creek Research Station, University of Washington located near Seabeck, Washington. Yearling fish were transferred to floating net-pens in seawater at the Manchester Field Station (NMFS) and reared for 3 years in seawater. In autumn the fish were checked for maturation, sorted by sex, and either retained in seawater net-pens or transferred by tank truck to freshwater tanks at the Northwest Fisheries Center. Experiments with maturing, virgin adults were conducted in 1983, 1984, and 1985. Stocks of Atlantic salmon used in each year were as follows: 1983, Gaspé (1978 brood year); 1984, Gaspé (1979 brood year); and 1985, St. John (1980 brood year). The peak time for spawning of untreated Atlantic salmon at these facilities is from the last week of October through the first week of November, based on data collected over 10 years.

The fish at the marine site were held in floating seawater net-pens that were 4.9 m^2 and 3.7 m deep. Two types of seawater net-pens were used: one had seawater (27 ppt); the other had a brackish water surface layer. The brackish surface layer was established and maintained by pumping creek water onto the surface of the water in a net-pen that had been fitted with a solid vinyl skirt of 1.8 m depth (Fig. 1). The salinity within the net-pen varied from 4 ppt at the surface to 27 ppt at the bottom of the skirt. The fish transferred to freshwater were kept in fiberglass tanks (3 m diameter x 1 m depth) in a flow-through system of dechlorinated Seattle municipal water. Temperature ranged from 11°C at the beginning of October to 9°C by early November.

1983 Experiment

Beginning in early October, maturing females (average body weight = 4.5 kg) were divided into six groups of about 10 fish per group. Three groups of 20

females each were either transported to freshwater, maintained in seawater (27 ppt) net-pens, or placed in a seawater net-pen with a brackish water layer (average salinity = 17–19 ppt in the top 1 m of the brackish water pen; Fig. 1). The fish were marked by cutting small triangular notches on the opercula to distinguish between controls and experimentals.

Test fish were injected intraperitoneally with D-Ala^6-Pro^9-NHethylamide-leuteinizing hormone-releasing hormone (GnRHa; Sigma Chemical Co., St. Louis, Missouri) dissolved in 0.9% NaCl at a dose of 25 μg/kg body weight. The injected volume was 0.5 mL/kg. Two injections were given, the first on 18 October and the second on 21 October. Control fish received injections of saline alone. The fish in freshwater were checked for ovulation on days 6, 7, and 9 after the first injection; the fish in seawater were checked on days 10, 13, and 16 after the first injection. When checking the fish for ovulation, the fish were netted from the pens and anesthetized in tricaine methane sulphonate (MS 222; 0.05%). Gentle pressure was applied to the abdomen to determine if eggs could be expressed. Expressed eggs were collected in plastic pails, placed in plastic bags, and maintained at 4–6°C for not more than 2 h until fertilization. Ovulation was determined to be complete if more than 50% of the estimated total number of eggs could be expressed. For fertilization, milt was collected from at least three males that were injected with GnRHa at the same dose and time schedule as the females. Milt collected from males was stored in a plastic bag at 4–6°C in a cooler until used to fertilize eggs (not more than 2 h).

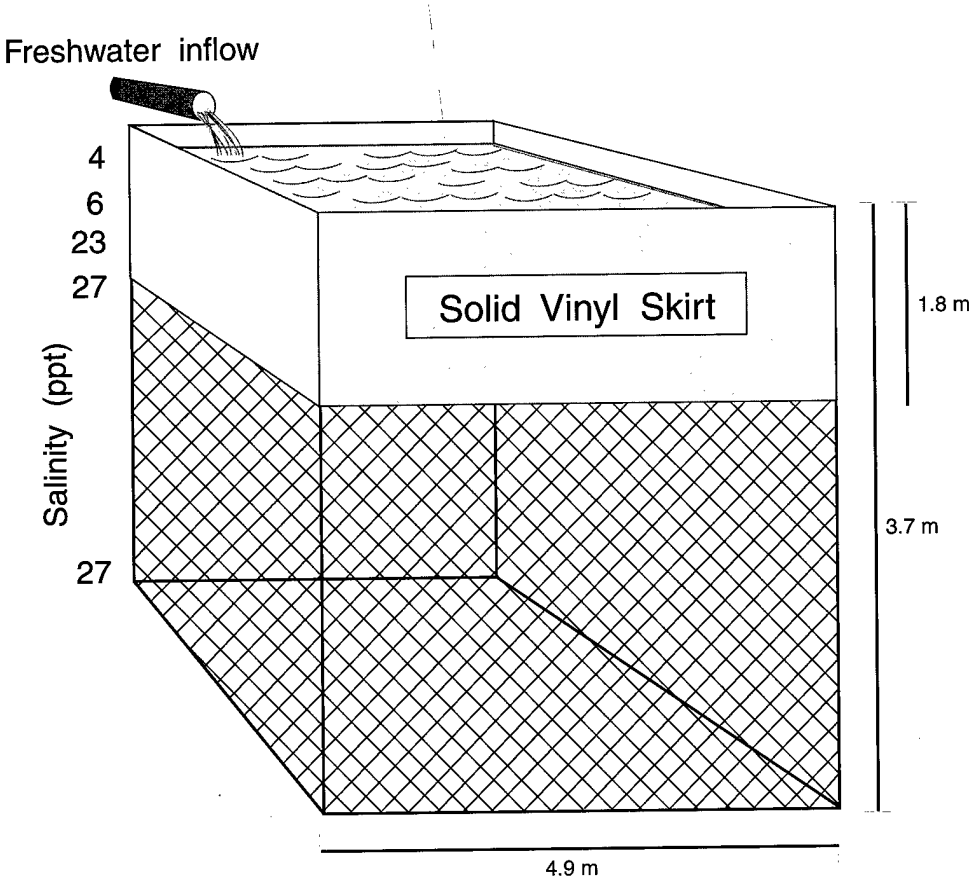

Figure 1. Floating seawater net-pen fitted with a solid vinyl skirt and freshwater supply for establishing a brackish surface layer of water.

Females in the seawater or brackish water net-pens were mated with males maintained in seawater; females held in freshwater were spawned with males held in freshwater. All eggs were fertilized at the Northwest fisheries Center in Seattle. Fertilized eggs were water-hardened and placed in incubator trays (Heath-Techna) perfused with dechlorinated Seattle municipal water at 7–9°C. Eggs from individual females were kept in separate groups, and data on number of mortalities in each group were recorded through hatching. The percent survival to hatch was determined for each female by dividing the number of hatched alevins by the number of eggs initially placed in the incubation tray.

1984 Experiment

At the beginning of October, maturing fish were sorted, marked, and placed in groups of about 10 fish and maintained in seawater, brackish water, or freshwater, as in 1983. The fish were given two injections of GnRHa at a dose of 10 μg/kg each. The first injection was on 12 October, the second on 15 October. The fish were checked for ovulation every other day beginning with day 5 after the first injection. Eggs were fertilized as described in the 1983 experiment.

1985 Experiment

At the beginning of October maturing fish were selected and injected intraperitoneally with passive integrated transponder (PIT) tags using a 12-gauge needle and syringe. The PIT tags allowed rapid identification of individuals by an external electronic detector that reads the unique code on the PIT tag microchip. The fish were either placed in a seawater net-pen containing a layer of brackish water as in the 1983 experiment, or they were transferred to freshwater. The fish were given two injections of GnRHa at either 2 μg/kg or 20 μg/kg. The first injection was given on 15 October, the second on 18 October. The fish were inspected for ovulation daily beginning on day 6 after the first injection. Eggs were fertilized as described in the 1983 experiment.

Statistics

Differences in the survival to hatch were evaluated by one-way analysis of variance followed by a Student-Newman-Keuls multiple range test (Zar 1974). The level of statistical significance was $P \leq 0.05$.

Results

1983 Experiment

The females injected with saline in freshwater were spawned from day 6 through day 9 after the first injection (Fig. 2). All fish injected with GnRHa in freshwater were spawned on the sixth day after the fist injection. None of the control fish in full-strength seawater net-pens had ovulated by day 16 after the first injection, when the experiment was terminated. Of the control fish in seawater with the brackish surface layer, 5 of 10 fish spawned on day 10 after the first saline injection. All of the GnRHa-injected fish in either seawater or brackish water had ovulated by day 10 after the first injection; day 10 was the first time after day 3 that the fish in the net-pens were checked for ovulation.

The survival to hatch of eggs from control and hormone-treated females in freshwater was greater than 78%. In contrast, the survival of eggs from females in the marine net-pens was less than 20%. Most of the eggs from the females in net-pens appeared water-hardened. We hypothesized that the females in net-pens had ovulated several days before they were first checked for ovulation on day 10 after the first injection. Females were checked for ovulation sooner and more frequently in subsequent experiments.

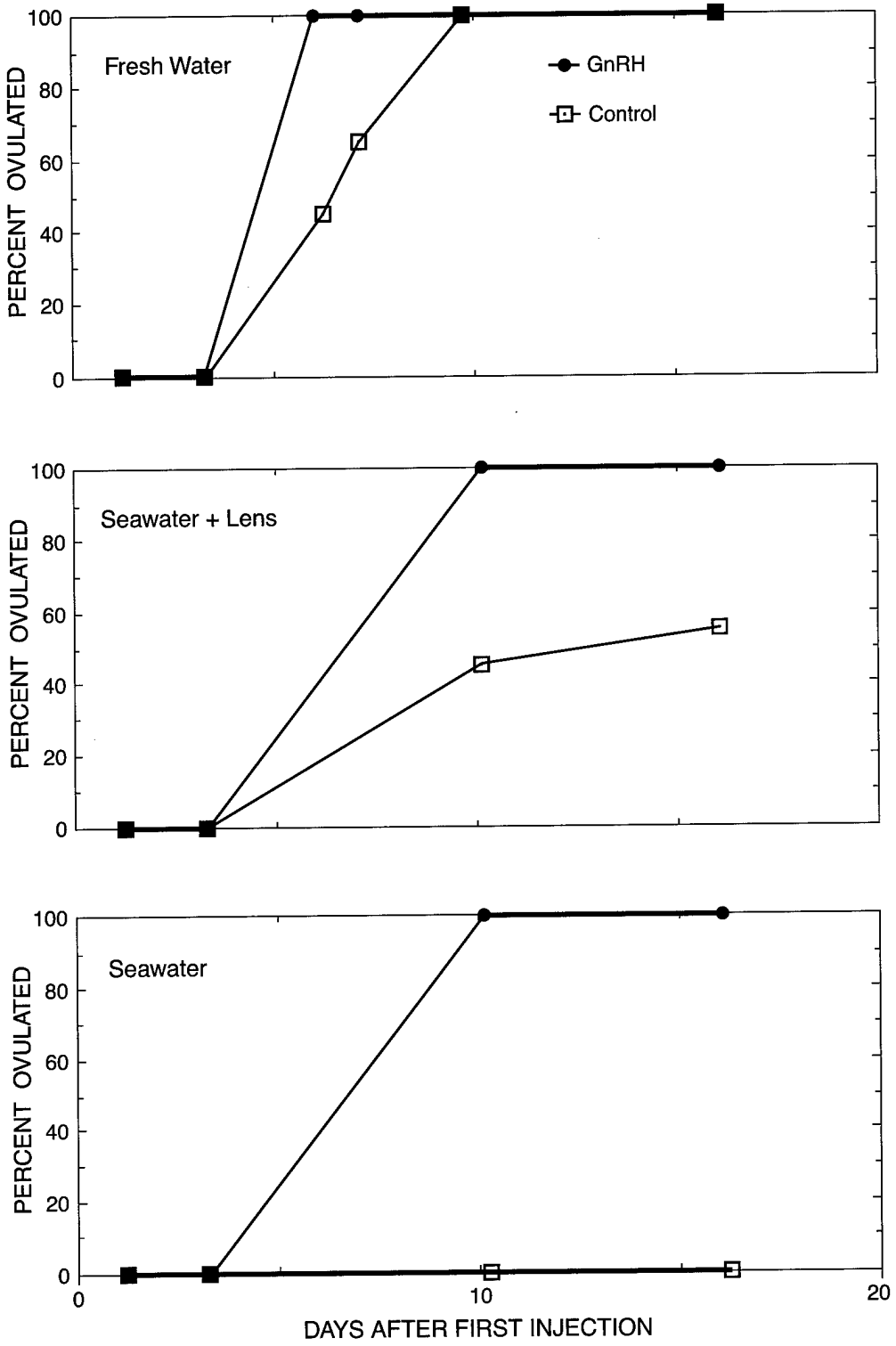

Figure 2. The effect of GnRH analogue injection (25μg/kg) on ovulation of Atlantic salmon held in either freshwater or saltwater net-pens with or without a brackish surface layer of water in the 1983 experiment.

1984 Experiment

The control (saline injected) females in freshwater were spawned between 14 and 21 days after the first injection, whereas GnRHa-injected females in freshwater were spawned between 7 and 15 days after the first injection (Fig. 3). All of the GnRHa- injected females in marine net-pens had ovulated by day 10 after the first injection. None of the control females in net-pens had spawned by day 21 after the first injection. The experiment was ended on day 21 postinjection.

Egg quality, as measured by survival to hatch of eggs from hormone-treated females, was not significantly different in any group for those eggs collected on day 7 after injection, although the mean value for fish in seawater was only 45% (Fig. 4). Egg survival from hormone-treated females in freshwater was 85% for females spawned on day 7 and 90% for those spawned on day 10 after the first injection (Fig. 4). Significantly lower egg quality was observed in groups of eggs collected on day 10 after the first injection from hormone-treated fish held in net-pens.

1985 Experiment

GnRHa-injected females in freshwater and in net-pens were spawned between days 6 and 10 after the first injection (Fig. 5). Ninety percent of the females injected with the 20 μg/kg of GnRHa spawned by day 6, whereas only about 30% of those injected with 2 μg/kg of the hormone were spawned. Control females were spawned between days 10 and 21 in freshwater and between days 15 and 21 in the net-pens with the brackish water lens. There were no groups of maturing fish maintained in only seawater in this experiment. Gamete quality was comparable in all groups based on survival to hatching (Fig. 6).

Discussion

GnRHa injections induced ovulation in Atlantic salmon held in freshwater or in marine net-pens with or without access to a brackish water surface layer. Although some commercial growers of Atlantic salmon have been successful in spawning female broodstock directly from seawater net-pens without using hormones, females held in our marine facilities very rarely ovulate. Novotny (1975) and Clarke et al. (1977) were able to obtain spontaneously ovulated eggs from coho salmon maintained in seawater. Weretheimer (1984) was able to obtain spontaneous ovulation in coho salmon and pink salmon (*O. gorbuscha*) held in seawater raceways or in estuarine net-pens (dilute seawater). For the coho salmon, survival to spawning was greater in the estuarine conditions (86–90%) compared with full strength seawater conditions (50–58%), and greater survival was also observed for the pink salmon in dilute seawater (Wertheimer 1984). In our studies, spontaneous ovulation was found more often in females held in net-pens with access to dilute (17 ppt) seawater compared with females held in pens in more concentrated seawater (27 ppt).

Injection of GnRHa facilitated ovulation in our Atlantic salmon in net-pens regardless of the salinity. Crim (1985) successfully used pelleted implants of GnRHa to induce ovulation of Atlantic salmon in seawater. On the other hand, Sower et al (1982) found that injection of hormones to induce spawning of coho salmon was less effective when the fish were held in seawater compared with freshwater.

Egg quality of the spawned females in net-pens, as assessed by survival to hatch, was reduced in the 1983 experiment and at day 10 after the first injection in the 1984 experiment. No differences in egg quality were observed between groups ovulated on day 7 after the first injection in 1984 or at any date in 1985. Low egg quality has been reported for coho salmon, Atlantic salmon, and pink salmon spawning in seawater or dilute seawater (Novotny 1975; Clarke et al. 1977; Sower et al. 1982; Wertheimer 1984; Crim 1985). Wertheimer (1984) found that gamete viability was inversely correlated with the osmolarity of blood, ovarian fluid, and seminal fluid. In our studies, low egg quality from females in net-pens was observed when the fish were infrequently examined for ovulation. In the 1985 experiment, females in net-pens were checked for ovulation more frequently (on days 6, 7, 8, and 10 after the first injection) that had been done in the previous 2 years. In the study by Sower et al. (1982), females in seawater were checked for ovulation only twice per week.

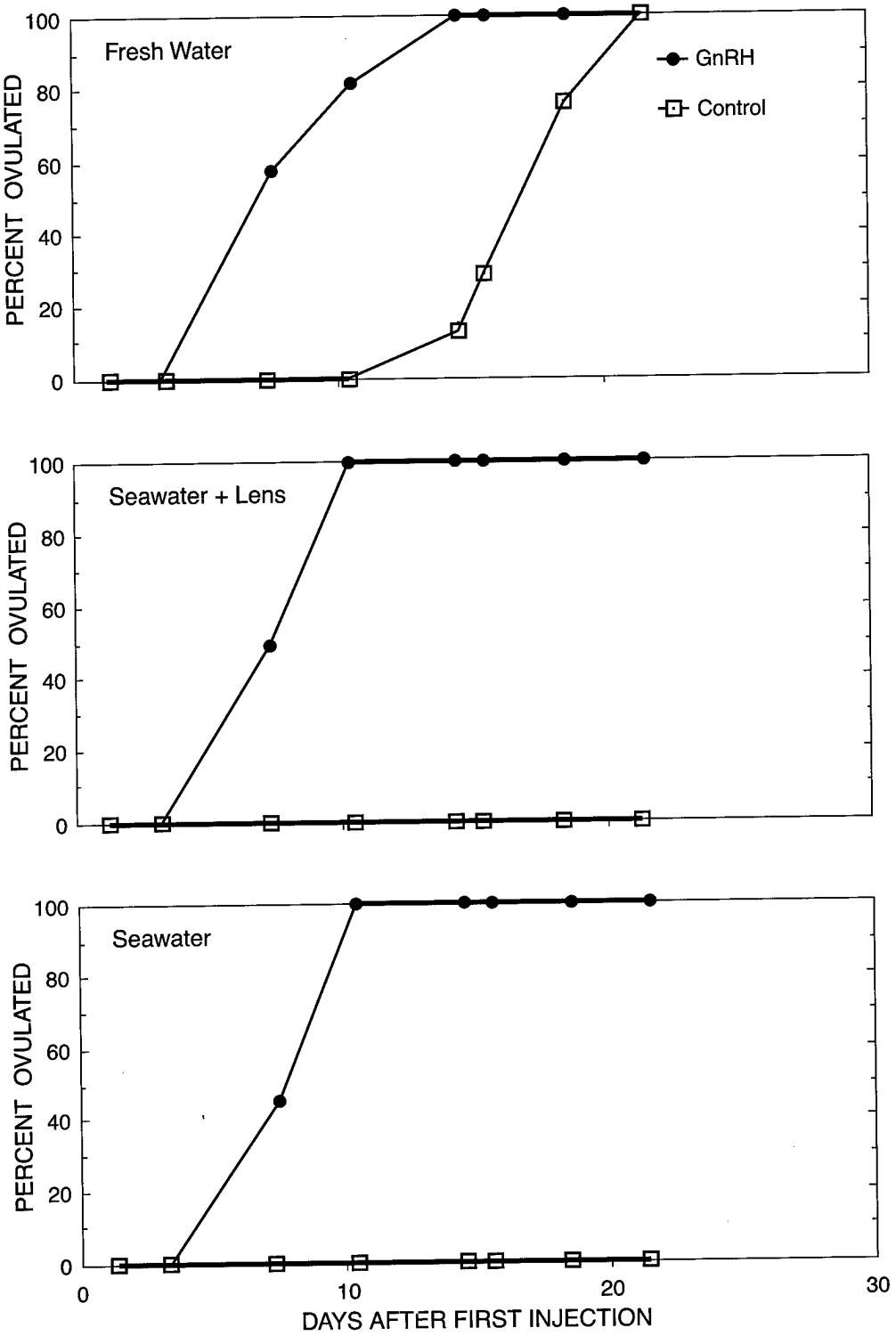

Figure 3. The effect of GnRH analogue injection (10 μg/kg) on ovulation of Atlantic salmon held in either freshwater or saltwater net-pens with or without a brackish surface layer of water in the 1984 experiment.

Although checking fish twice per week is a typical frequency for spawning fish in freshwater, it may be too infrequent for fish held at high salinities. We hypothesize that maintaining fish in seawater for more than 24 h after ovulation may have detrimental effects on the eggs. The basis of such a detrimental effect was not determined, although the evidence indicates that high osmolarity of ovarian fluid may be a problem (Wertheimer 1984). The osmolarity of fish tissues of fluids was not determined in our study. However, we observed that the fish in the pens with the brackish water layer were frequently found in the top meter of the water column, unlike the fish in the seawater net-pens, which indicates that the fish were showing a behavioral preference for lower salinity water. Female ovulation in net-pens in our experiments did not lack ovarian fluid, as has been reported for coho salmon spawning in seawater (Sower et al. 1982). Therefore, we recommend that fish be checked daily for ripeness beginning on day 6 after the first injection of GnRHa. Furthermore, based on these and other data, fish that do not ovulate by day 12 after the first injection probably will not spawn in response to the GnRHa. An additional series of GnRHa injections should be initiated by day 14.

Acknowledgments

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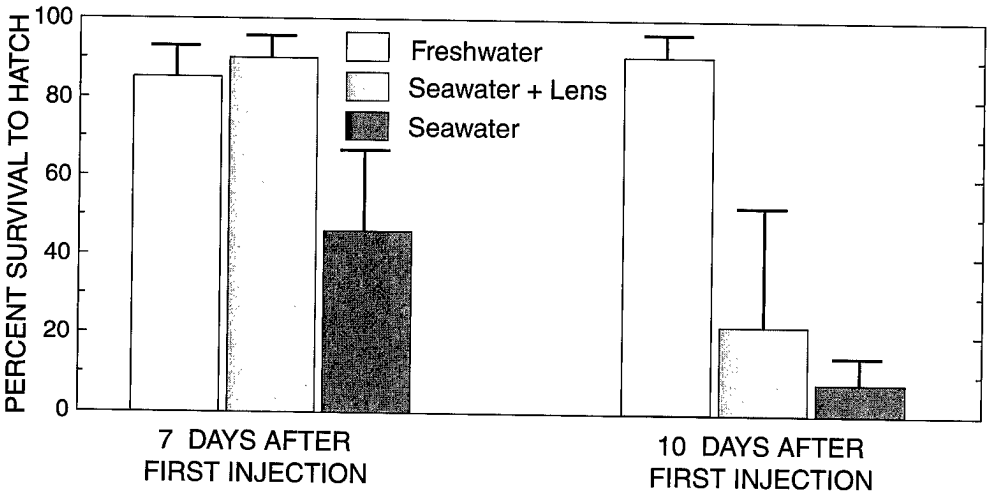

Figure 4. Percent survival to hatch of eggs from females in freshwater, seawater, or seawater with access to a brackish water lens in the 1984 experiment. Bars and brackets indicate mean ± standard error, N = 4.

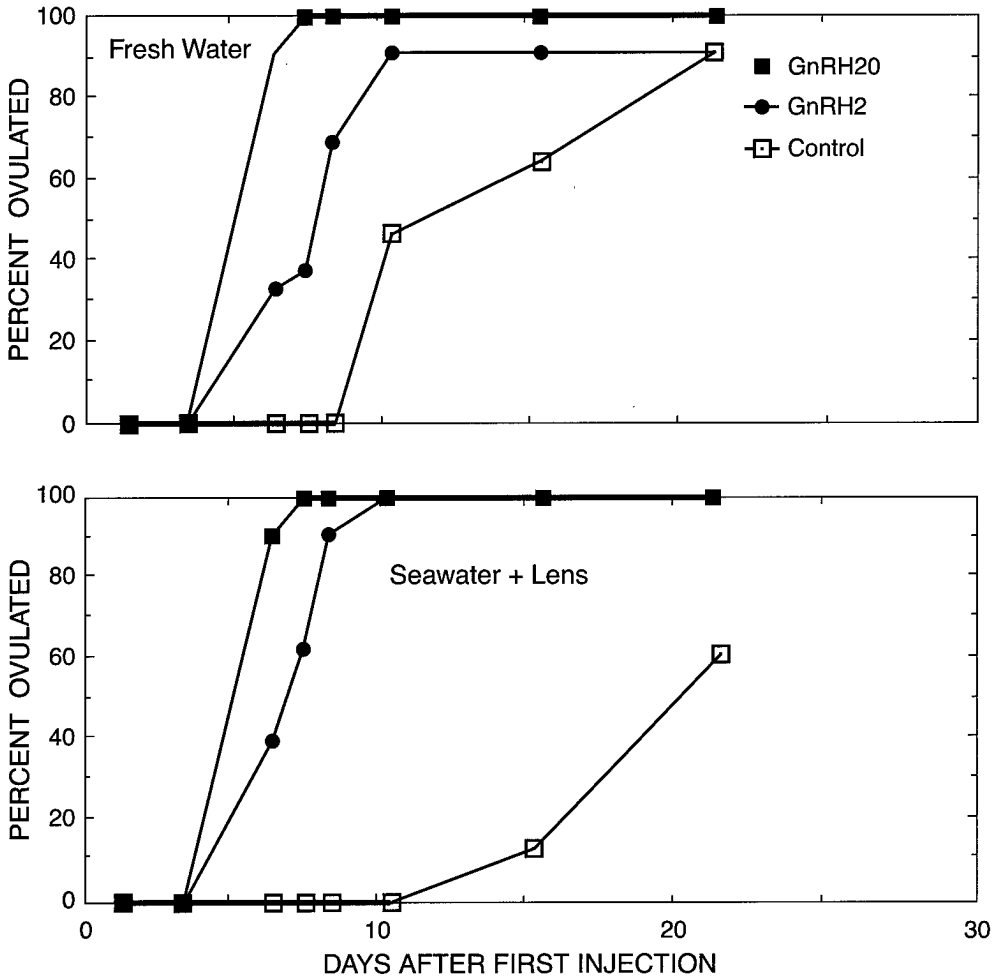

Figure 5. The effect of GnRH analogue injection (2 or 20 μg/kg) on ovulation of Atlantic salmon held in either freshwater or seawater net-pens with a brackish surface layer of water.

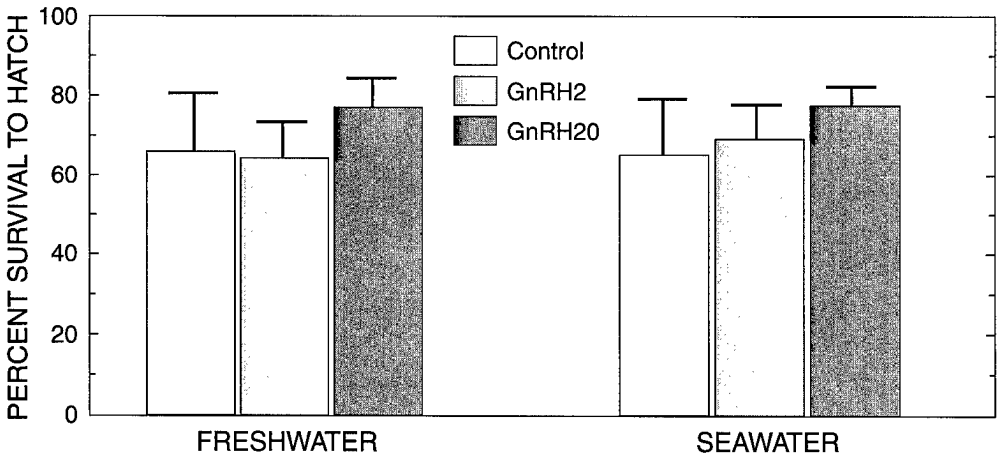

Figure 6. Percent survival to hatch of eggs from females in freshwater or seawater with a brackish surface layer of water in the 1985 experiment. Bars and brackets indicate mean ± standard error, N = 8.

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Exploitation and Management of Atlantic Salmon in the Northwest Atlantic

by

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Abstract. Restoration of Atlantic salmon (*Salmo salar* L.) in the United States began in 1947, but the process accelerated in 1984 with the start of a 25-year program to restore Atlantic salmon in New England. Atlantic salmon are worth $2.6 to $4.3 billion in terms of total economic benefits to the United States; they will cost $340 million to restore. As many as 17 fish culture facilities are producing annually 1.4 million smolts, 1.2 million parr, and over 4 million fry for stocking. Ocean feeding migrations take these young salmon through fisheries off Newfoundland, Labrador, and West Greenland, where many of the maturing salmon are caught in the interceptory fisheries in their second summer at sea. Tagging studies begun in 1966 have provided information on migration routes and interception mortalities. Since 1968 the interception fisheries have caught 2.5 (Canada) and 3.3 (West Greenland) times as many salmon as have been caught by anglers in the United States. Over the past 20 years Canada has annually caught 47% as many Atlantic salmon as have returned home to Maine rivers. The West Greenland fishery has caught 62% as many Atlantic salmon annually as have returned home.

The population sizes of Atlantic salmon returning to Maine would have been 2.1 times as large, on the average, as they were if these interceptions had not occurred and if the fish did not suffer unusual mortality on the way home. Exploitation rates at West Greenland were estimated to be only about 33% in the 1970's. Analysis of U.S. Carlin tagging data indicates that the exploitation rates for the spring, summer, and fall fisheries have been 0.10, 0.44, and 0.12, respectively averaged over 1967–87. Analysis of coded wire tagging data indicates that exploitation rates may have increased recently to as much as 70% in West Greenland waters. Exploitation rates in Canada seem to be lower and have declined in recent years.

In 1984, the North Atlantic Salmon Conservation Organization was established to promote the conservation, restoration, enhancement, and national management of Atlantic salmon throughout the North Atlantic. Total allowable catch limits were set at West Greenland. In Canada, reductions in fishery seasons were imposed, and specific fisheries, such as the commercial fisheries off Nova Scotia, were closed completely. Canada also reduced fishing effort using a buy-back license program. Exploitation rates were reduced within the home rivers by strong management plans in Canada and the United States. No multi-sea-winter salmon were allowed to be killed in many Canadian rivers, and in-river survival increased from 30% to 75% in index rivers.

Despite increased stocking in the United States, and more management restrictions in Greenland, Canada, and the United States, returns of multisea-winter salmon (those susceptible to interception fisheries) continue at the same level or have declined.

Atlantic salmon (*Salmo salar* L.) once occurred in great abundance in New England. In pre-Colonial days, 300,000 to 500,000 salmon returned to 28 to 34 river systems (Fig. 1) in New England every year (Pearson 1972). By 1865, Atlantic salmon runs in southern New England had disappeared. Since that time only sever rivers in the United States, all in the State of Maine, have sustained relatively stable populations of Atlantic salmon. Today large amounts of money are being spent to restore the Atlantic salmon to New England.

Atlantic salmon are worth $2.6 to $4.3 billion to the United States in terms of total economic benefits (Edwards 1989), and the present value of salmon restoration costs calculated over the period 1960 to 2012 is $340 million (Edwards 1989). Efforts to restore Atlantic salmon date back, at least, to 1947. The Atlantic Sea-Run Salmon Commission of Maine was formed in that year to study and restore salmon runs to Maine rivers. In 1965 the U.S. Congress enacted the Anadromous Fish Conservation Act, which expanded and accelerated efforts to restore Atlantic salmon. The program increased significantly in 1984 with the start of a 25-year program to restore Atlantic salmon in New England. State and federal agencies planned to increase adult returns eight-fold from the 1984 level in 18 river systems (U.S. Federal and Wildlife Service 1984). Today the restoration effort has grown into a highly coordinated initiative involving nine state and three federal agencies, as well as private and public sector groups. Although Atlantic salmon returning to major river systems in the United States number less than 6,000 annually, they now enter 16 river systems, including the Merrimack, Pawcatuck, and Connecticut Rivers in southern New England. Restoration activities have included research, fish culture, fish passage facilities, habitat enhancement, pollution control, and conservation measures. There are 17 fish culture facilities currently involved in the New England Atlantic salmon restoration effort, including 10 hatcheries, two kelt (post spawner) conditioning facilities, three smolt release facilities, and two sea run adult holding facilities (U.S. Fish and Wildlife Service 1984). The fish culture program has the projected capacity to produce over 5.5 million salmon annually. At present, 1.4 million smolts and 1.2 million fry are produced annually. Stocking of parr and smolts in U.S. rivers has increased from about 70,000 parr and 64,000 smolts in the early 1960's to over a million parr and one and a half million smolts by 1988. Fry stocking began in the 1970's and increased to over 4 million annually by 1988 (Fig. 2).

The populations of Atlantic salmon increased in abundance initially but the increases did not continue as expected (Table 1). The restoration plan released by the U.S. Fish and Wildlife Service projected a run of 10,000 fish by 1990 and 40,000 by 2005 (U.S. Fish and Wildlife 1984). Figure 3 shows the decline in catches in the native wild rivers of Maine where dams have been removed, where fishways have been installed, where habitats have been improved or remained the same, and where some stocking has supplemented existing populations. Salmon runs in 1987–88 for Maine rivers were especially disappointing. Rivers with wild salmon runs produced catches that were 68% below the annual average for the previous 20 years (Anonymous 1989b). Ratios of grilse to multisea-winter fish were the highest on record in 1987 and 1988. Despite increased stocking, the numbers of large salmon, which are those that are susceptible to interception fisheries, have not returned to their natal rivers in the same proportions as the grilse salmon. Until they do, we cannot assume that restoration has been successful.

The National Marine Fisheries Service (NMFS) began an Atlantic salmon research program in 1983 and began to look at the exploitation of U.S.-origin salmon in the interception fisheries off Canada and Greenland. It was clear that the success of the restoration program in New England would depend to a large degree on the level of harvest in these fisheries. In an effort to address the exploitation rates of Atlantic salmon by intercepting fisheries, the Convention for the Conservation of Salmon in the North Atlantic Ocean was ratified by six nations and came into force in 1983. The North Atlantic Salmon Conservation Organization (NASCD) was created in 1984 as part of this treaty for the purpose of managing salmon through a cooperative program of conservation, restoration, and enhancement of Atlantic salmon stocks. The principal means for achieving these goals under NASCO is through a system for controlling the exploitation in a given fishery by one member country on salmon that originate within the territory of another member nation. Nine salmon-producing and salmon-harvesting nations are now members of NASCO.

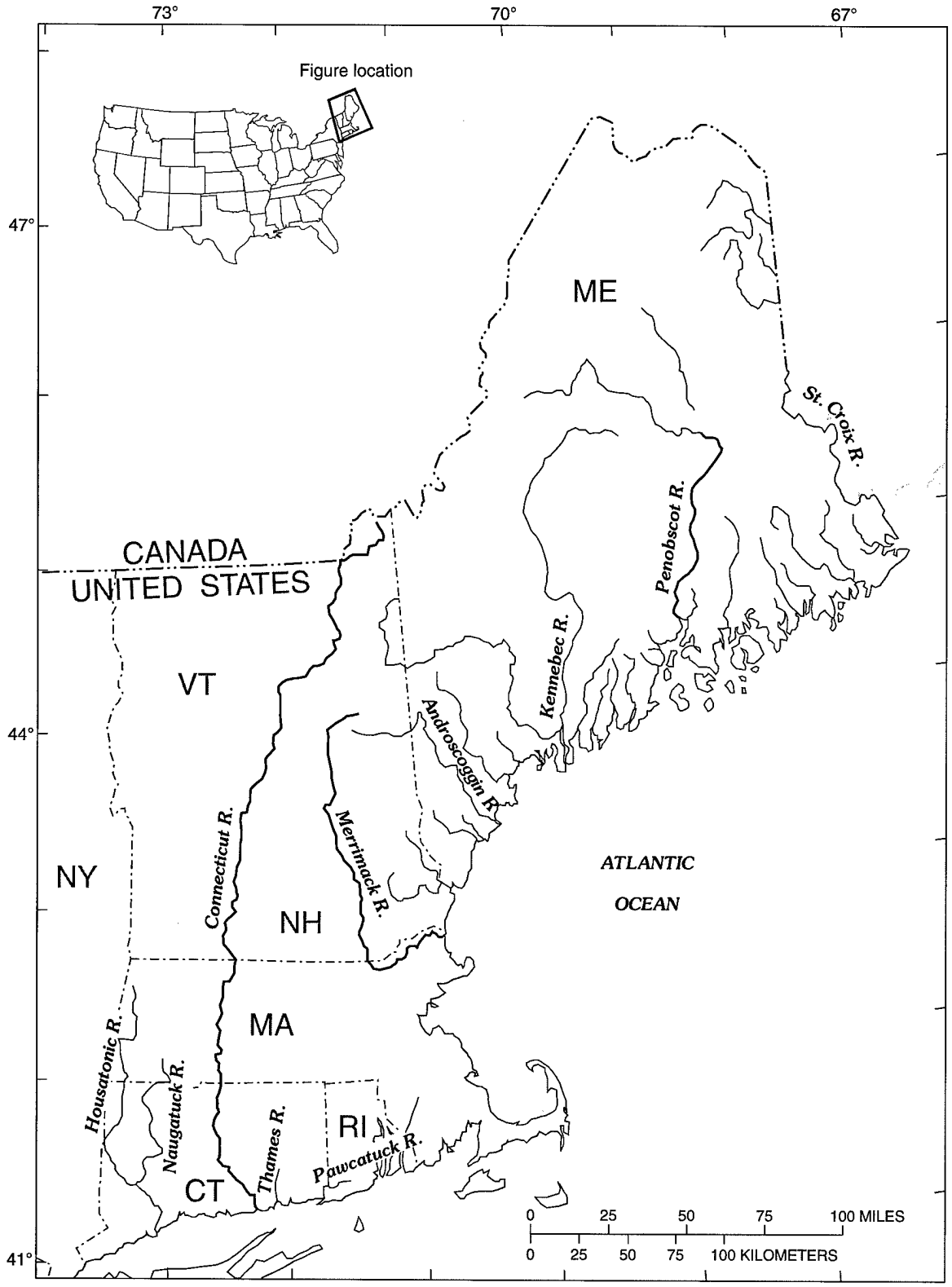

Figure 1. U.S. rivers that once contained Atlantic salmon, showing the present three index rivers -- Connecticut River, Merrimack River, and Penobscot River.

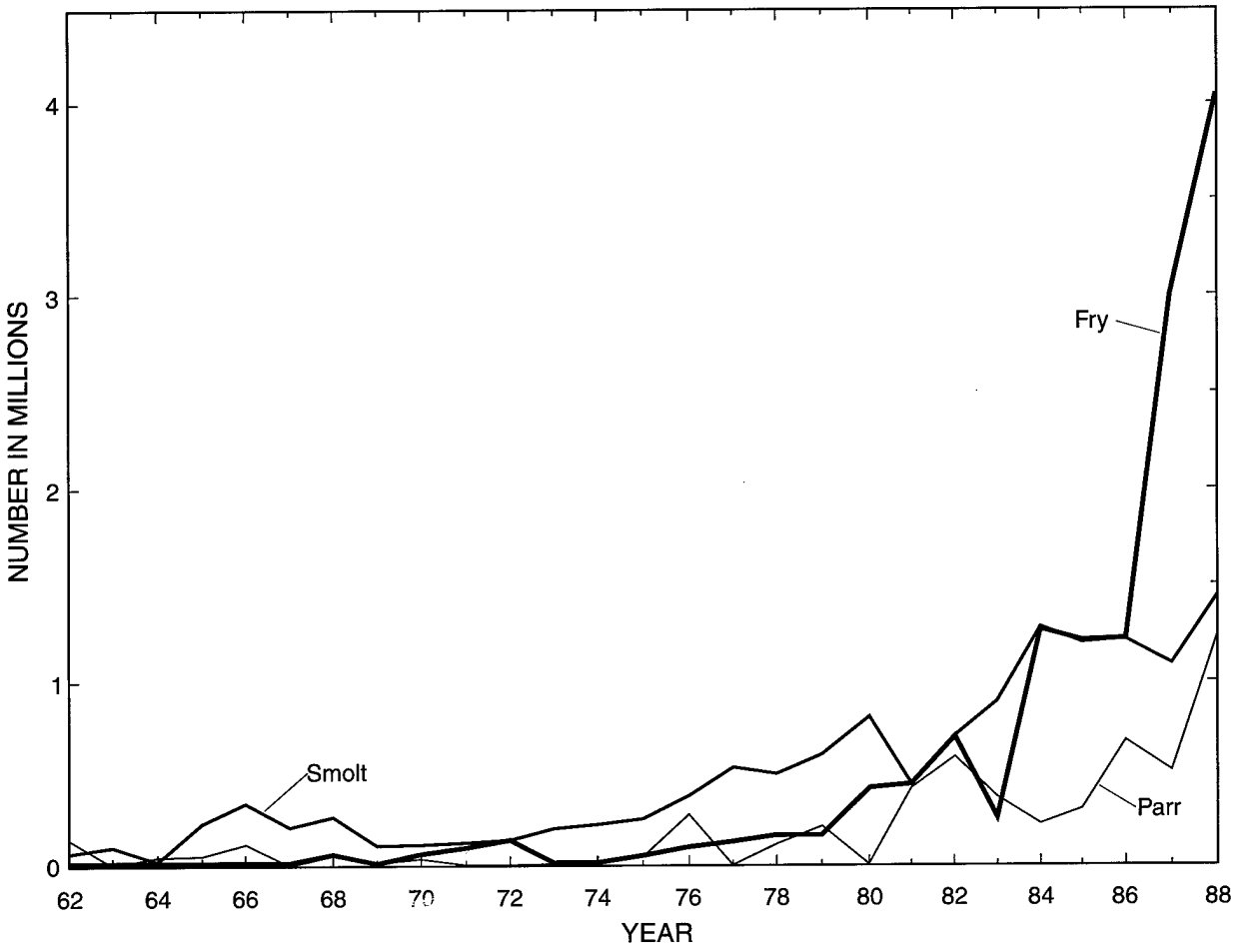

Figure 2. Number of fry, parr, and smolts stocked in U.S. rivers.

Table 1. Run size (two-sea-winter salmon) in U.S. rivers

Year of return	All Maine	Connecticut River	Merrimack River	Pawcatuck River	Total number
1967					946
1968					664
1969					634
1970					787
1971					637
1972					1,328
1973					1,378
1974	1,306	1			1,307
1975	2,183	3			2,186
1976	1,222	2			1,224
1977	1,920	7			1,927
1978	3,853	93			3,946
1979	1,773	58			1,831
1980	5,225	175			5,400
1981	4,725	529			5,254
1982	5,440	70	23	38	5,571
1983	1,773	39	114	38	1,964
1984	2,793	92	104	26	3,015
1985	4,319	310	212	1	4,842
1986	4,892	318	103		5,313

This paper is a review of recent efforts to understand the degree of exploitation in these intercepting fisheries and to explore the management achieved. Much of the science has been conducted in International Council for the Exploration of the Sea (ICES) Working Group sessions, which are held annually and report in ICES assessment documents. Much of what follows has been discussed within these working groups. The reader is referred to these documents for more details.

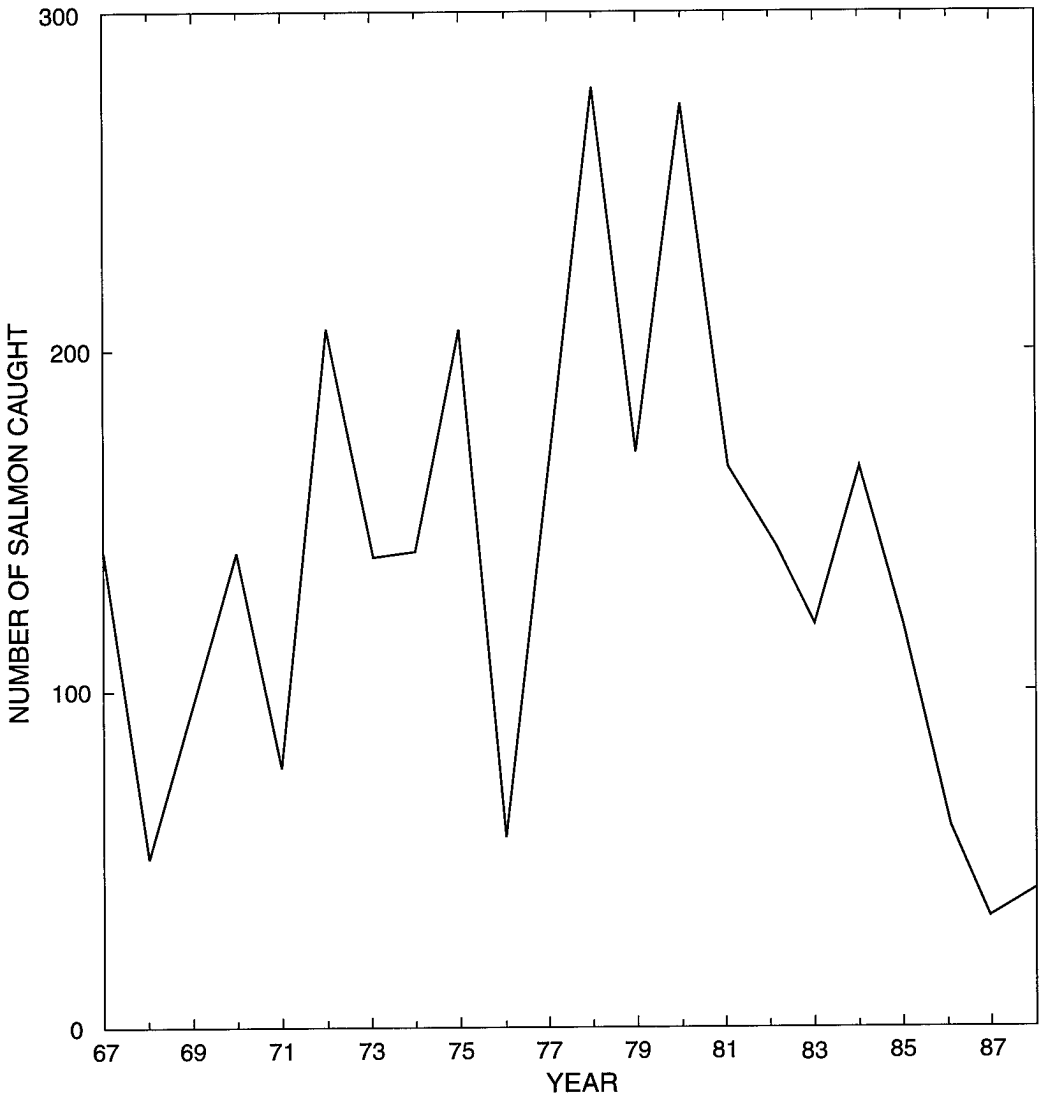

Figure 3. Recreational catch of two-sea-winter Atlantic salmon from Maine wild rivers.

Tagging Studies

An analysis of tag recovery data was undertaken in the mid-1980's in an attempt to understand the migrations, amount of harvest, and mortality rates on U.S.-origin salmon during their several years of feeding in the ocean. In 1966, the Maine Atlantic Sea-Run Salmon Commission began tagging salmon smolts with external Carlin tags (Table 2). Since 1966, about 1.5 million Atlantic salmon hatchery-reared smolts have been tagged with external Carlin tags and released into New England rivers. In 1984, the Maine Atlantic Sea-Run Salmon Commission and the NMFS began an analysis of the extensive Carlin tag recoveries from these Maine-origin salmon and doubled the numbers of fish tagged in Mane rivers (Table 2). This tag is a small, oval plastic disc marked with a reward message and an identity number, which is attached to the back of salmon smolts prior to their release. Fishermen who catch a tagged salmon may return the tag for a $15.00 reward. Carlin tags are expensive to apply and cause some smolt mortality. Fishermen who catch the fish are often reluctant to return the tags, and the reporting rate has to be assumed when the data are analyzed. Carlin tagging remains, however, the most important source of data for studying the migration and exploitation of U.S.-origin salmon because migration information is possible from any location where they are caught by fishermen.

Table 2. Summary of U.S. Carlin and coded wire tag (CWT) releases (thousands also includes some parr CWT salmon)

	Carlin			CWT's			
Year	Maine	Connecticut	Total	Maine	Connecticut	Merrimack	Total
1966	83	0	83	0	0	0	0
1967	83	0	83	0	0	0	0
1968	78	0	78	0	0	0	0
1969	78	0	78	0	0	0	0
1970	49	4	53	0	0	0	0
1971	30	0	30	0	0	0	0
1972	62	0	62	0	0	0	0
1973	38	25	63	0	0	0	0
1974	44	50	94	0	0	0	0
1975	29	42	71	0	0	0	0
1976	25	2	27	0	0	0	0
1977	49	47	96	0	0	0	0
1978	0	25	25	0	0	0	0
1979	60	0	60	0	0	0	0
1980	50	0	50	0	0	0	0
1981	50	0	50	0	0	0	0
1982	50	0	50	0	113	0	113
1983	50	0	50	0	86	0	86
1984	100	44	144	0	100	0	100
1985	100	45	145	0	35	150	185
1986	100	40	140	100	147	50	297
1987	100	50	150	100	176	150	426
1988	100	50	150	100	354	150	614
1989	50	0	50	200	250	150	700
Total	1,458	424	779	500	1,261	650	2,511

In 1982, coded wire tagging also began as an alternative to Carlin tagging (Table 2). Coded wire tags (CWT) have been applied to smolts released in the Connecticut and Merrimack rivers from 1982 to 1985 by the U.S. Fish and Wildlife Service (FWS) in cooperation with state agencies. In 1985 the NMFS became involved in the use of CWT's and encouraged their use in Maine rivers. From 1985 to 1989 the program expanded under NMFS encouragement and funding until 700,000 salmon smolts were tagged and released in 1989 (Table 2). Coded wire tags have been used extensively in mark and recapture experiments with Pacific salmonids and were recommended by the IGES North Atlantic Salmon Working Group as another technique for the discrimination of salmon stocks in the interception fisheries (Anonymous 1987). Coded wire tags are small, cylindrical pieces of magnetized metal, etched with country of origin codes which are implanted in the snouts of salmon smolts prior to their release. Smolts receiving CWT's have their adipose fin removed for field identification. Coded wire tags can later be detected in adult salmon with the aid of a magnetic field detector and removed from the snout, allowing positive identification of the salmon's origin. Estimation of harvest from CWT's is free of the problem of nonreporting by fishermen, which is so important with Carlin tags, but CWT's must be recovered directly from the fishery by scientists, and thus they require the deployment of an expensive field recovery program. The recoveries also provide little new information on migration routes. Coded wire tags are easily and cheaply applied, however, and do not cause any significant smolt mortality.

The NMFS Northeast Fisheries Center supports an Atlantic salmon tag clearinghouse for the centralized coordination of tag returns and dissemination of tag return data to interested groups. In 1989 a lottery system was initiated with NASCO for the enhancement of tag returns. As regulations become restrictive the reporting rate of recovered tags will decrease, and the CWT program will become more important.

Migrations and Distribution

After leaving their rivers of birth or rivers where they are stocked, Atlantic salmon smolts undergo extensive feeding migrations while at sea. Figure 4 indicates, in a simple way, the movement of smolts or post-smolts to Newfoundland, then the general movement north of one-sea-winter fish to Labrador and Greenland and then their return. Much remains to be learned about the migrations, especially the post-smolt migrations. Most commercial fisheries do not utilize gear that would retain these small fish, so only occasional returns have been noted. Most post-smolts have been recovered in the Bay of Fundy and along the south shore of Nova Scotia during July (Meister 1984). These areas have weirs or tarps used for catching small herring, which are also very good sampling devices for young salmon. Some post-smolts are taken in the fall in these areas and other post-smolts have been caught off Newfoundland and Labrador 1,931 to 2,253 km from their home river after only 3 months at large. Salmon are thought to overwinter in the Labrador Sea north of the Grand Bank area (Reddin 1988). In spring, depending on temperature, salmon that have spent one winter at sea move into the Newfoundland coast. These salmon are moving from east to west, which probably reflects that they overwintered east of Newfoundland. Most of the salmon arrive in Statistical Areas A-D (Fig. 5), but a few are also caught on the south and east coasts. Figure 6 compares the number of total tag returns over the period of 1967–87 by area of catch in Labrador and Newfoundland. Most of the tags have been recovered in Labrador and Statistical Areas A and B in Newfoundland. Table 3 compares the Carlin tag returns of Maine-origin salmon by fishing areas in the North Atlantic. Nearly eight times as many tags have been returned from salmon caught in Areas A–D as in all other areas of Newfoundland, although in some years catches of Maine-origin salmon in other Newfoundland areas are significant. These fish are taken mostly in early July when migrating north to Labrador or Greenland and are assumed not to be available to the fishery in Areas A–D. The catches by area and week are shown in Table 4 and Fig. 7. These data are summarized over a 20-year period (1967–87), but overall migrations vary little from year to year. Fish appear in the middle of May in Areas C and D, 2 weeks later in Area B, and another week later in Area A during the first part of June. The spring recoveries reach their peak in all four areas during the first part of July and end by the middle of August as the salmon move farther north. The fish reach southern Labrador (Areas 51 and 52) by mid-June and northern Labrador during the first part of July. Peak recoveries occur during the third week in July in Labrador Areas 50, 51, and 52, while the maximum numbers appear in northern Labrador (Area 53) 1 month later.

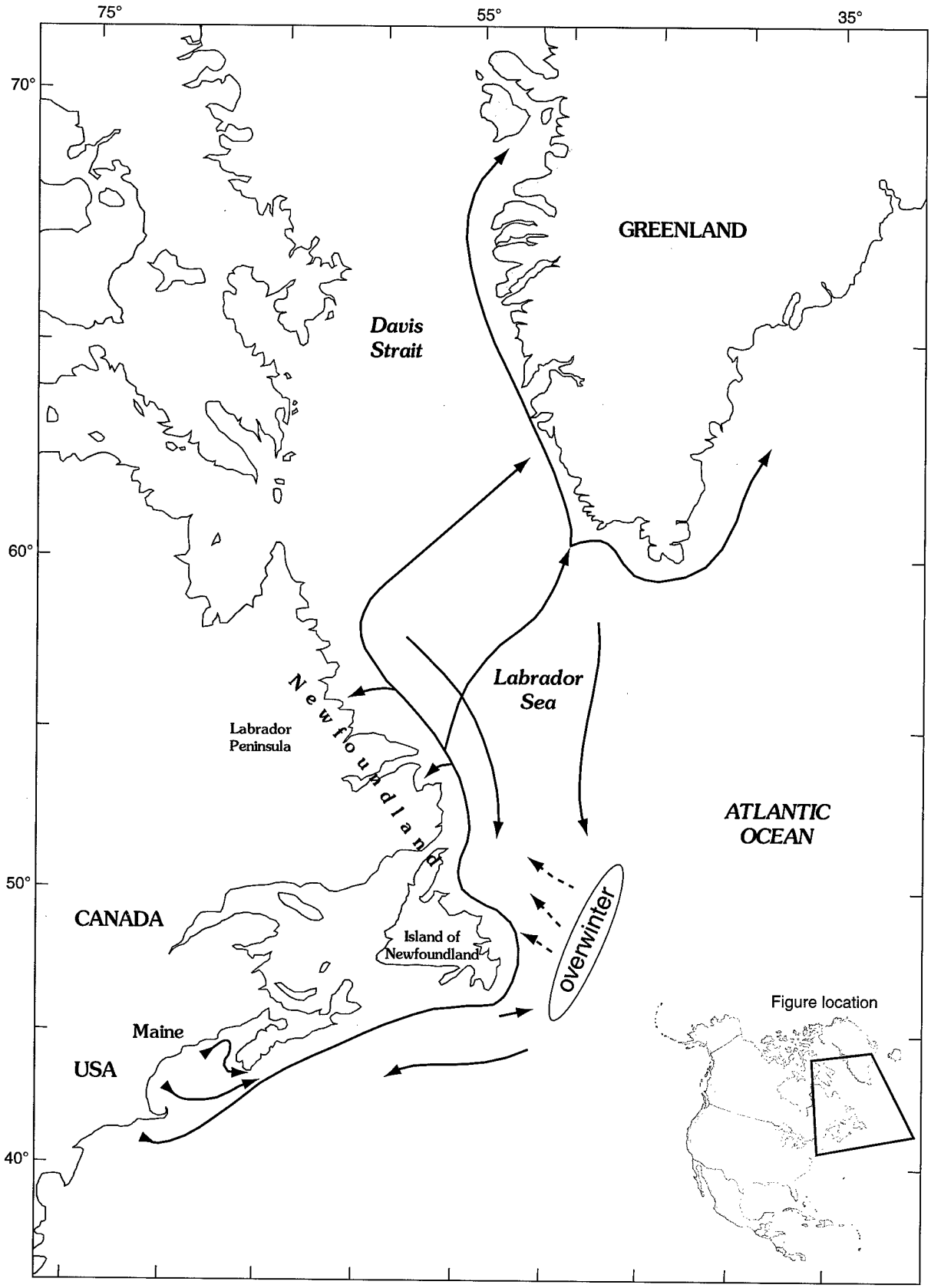

Figure 4. A simple representation of U.S. salmon migrations.

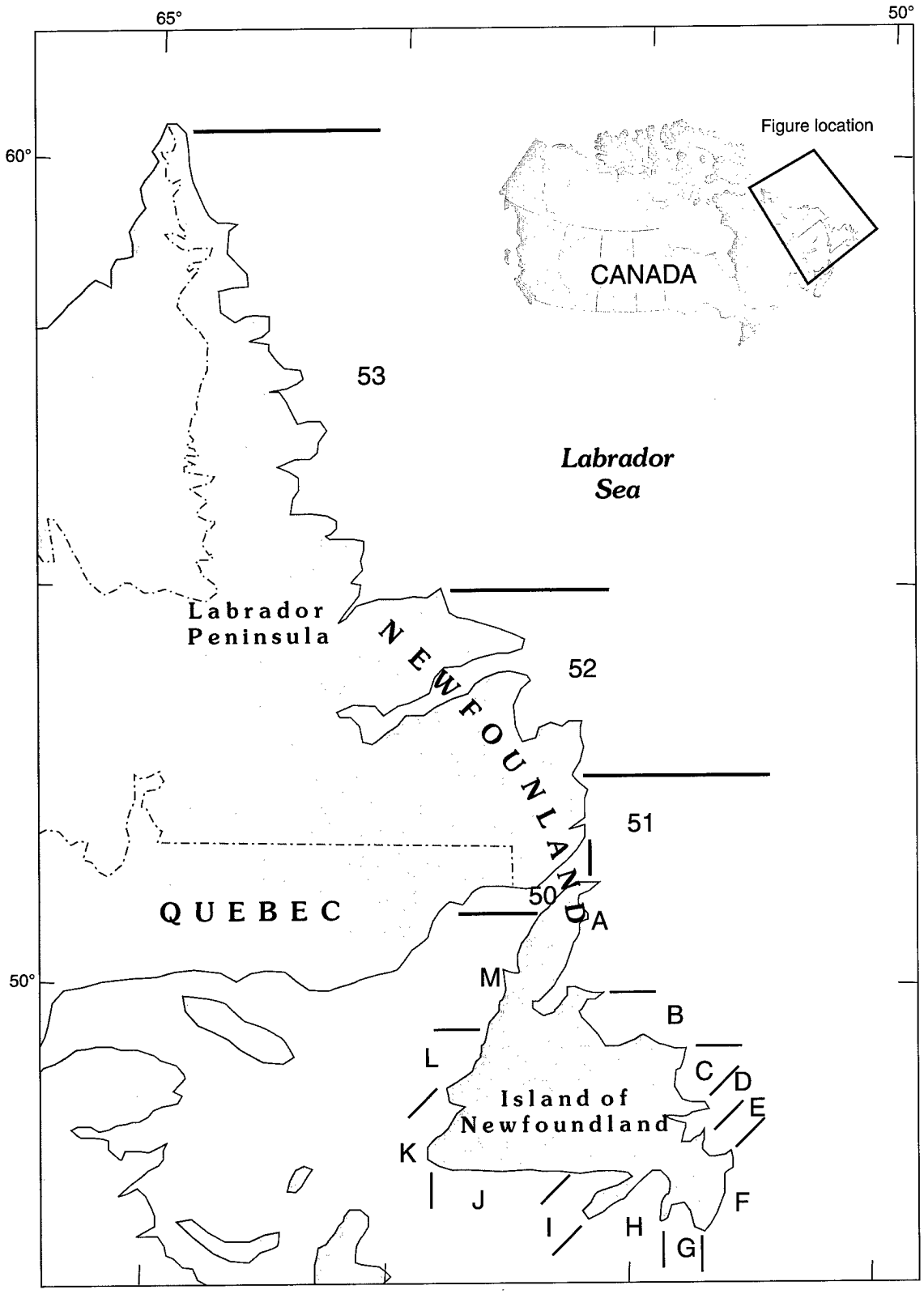

Figure 5. Statistical areas for reporting of catch and tag returns at Newfoundland and Labrador.

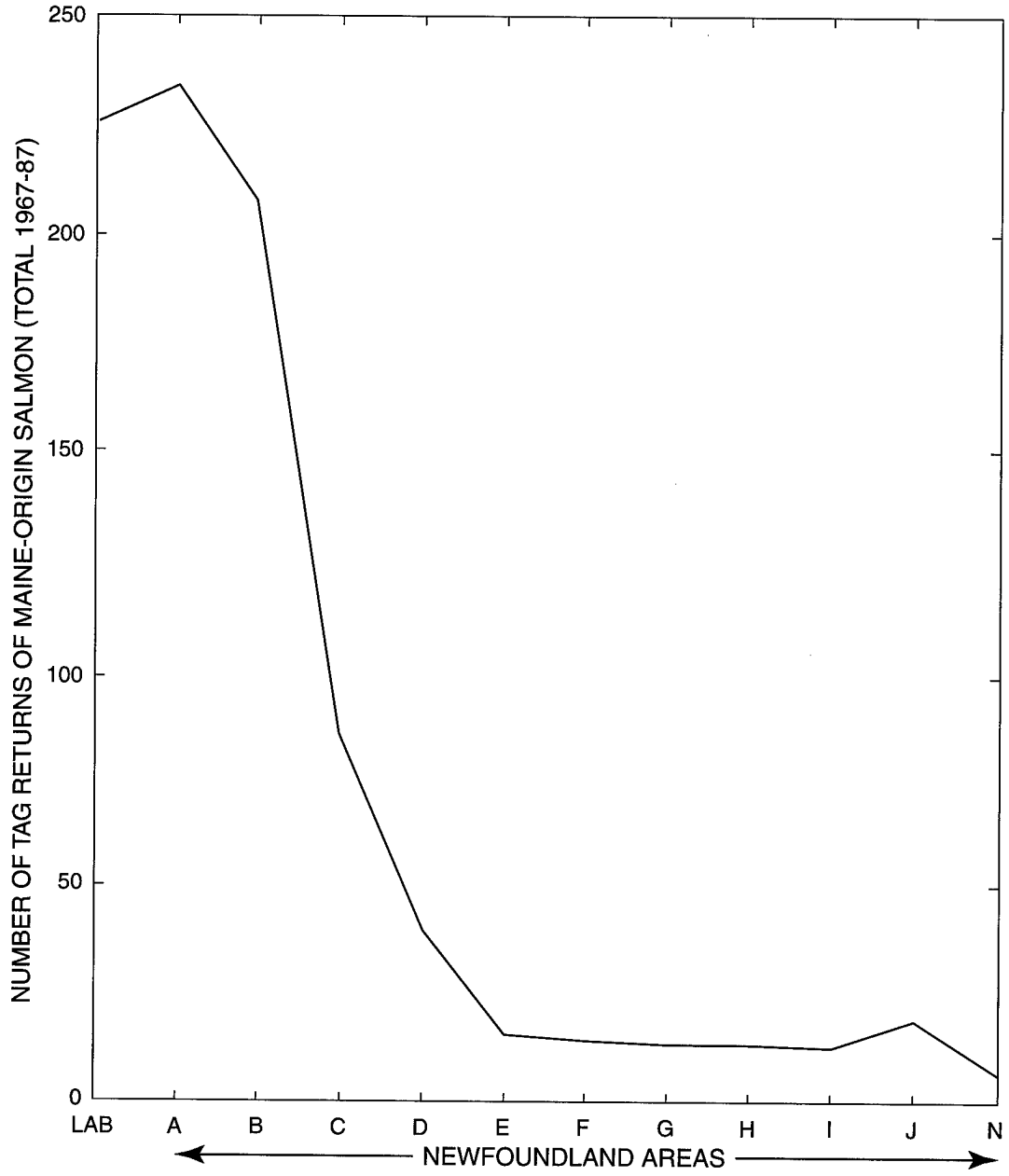

Figure 6. Number of tag returns of one-sea-winter Maine-origin salmon from Labrador and Newfoundland.

Table 3. Number of Carlin tag returns from Maine-origin salmon over the period 1967–1987

	Newfoundland		Other				
Year	Area A–D	Area E–N	Labrador	Canada	West Greenland	East Greenland	Maine
1967	26	8	4	4	37	0	0
1968	3	0	0	5	0	0	145
1969	2	1	0	2	6	0	6
1970	20	2	7	2	58	0	11
1971	35	1	12	3	382	7	58
1972	4	1	7	0	82	0	272
1973	12	6	7	1	131	0	176
1974	81	15	7	4	357	4	183
1975	73	9	20	2	127	0	384
1976	51	5	24	13	39	0	157
1977	11	2	3	1	11	0	83
1978	1	0	4	1	9	0	83
1979	0	0	0	0	0	0	31
1980	212	20	82	11	72	0	0
1981	24	2	15	1	40	0	403
1982	54	9	22	4	49	0	244
1983	17	0	9	1	7	0	119
1984	20	3	16	1	23	0	52
1985	63	5	25	0	58	6	158
1986	9	1	11	0	72	2	263
1987	28	4	16	1	165	0	102
1988	7	2	9	0	0	9	272
1989	0	0	0	0	104	0	0
Unknown	1	1	1	0	26	0	0
Total	754	97	301	57	1,855	28	3,202

Table 4. Harvest estimates of one-sea-winter Maine-origin Atlantic salmon for Canada and West Greenland (total catches over 1967–1987, not smoothed)

Standard weeks	Dates	Newfoundland area			Labrador area				West Greenland area		
		C&D	B	A	50	51	52	53	1C&1D	1E&1F	1A&1B
20	May 20–24	17									
21		11									
22	May 03–28	65	13								
23		56	77	10							
24	Jun 11–17	109	87	68			13				
25		184	167	287			34			7	
26		206	279	653			10				
27	Jul 2–8	413	410	1,215			162	13			
28		267	509	1,177			287	62	17		7
29	Jul 16–22	151	357	602			133	57	111		
30		108	192	481			312	215	148	124	
31		125	83	257			88	364	899	226	27
32	Aug 6–12	50	8	11			76	807	1,165	458	93
33			61	77			38	477	1,065	577	288
34	Aug 20–26			60			61	607	994	701	292
35		11	17					263	1,244	702	480
36							44	285	816	353	806
37	Sep 10–16		17					199	569	136	463
38		8	17					155	379	163	535
39							21	78	364	59	411
40	Oct 1–7	11						21	264	59	241
41			39	53					167	46	129
42		102	83	193					127	7	70
43		35	73	103				34	108		65
44		128	476	267					130	10	133
45	Nov 5–11	179	586	80					142		
46		125	730	285					14		45
47		30	317	46							34
48		68	302	102							
49	Dec 3–9	87	226					59			13
50		51	71	13							
51		25	1	7							
52			8					12			
Unknown		329	680	487			61	189	1,031	418	5,279
Total		2,951	5,886	6,534			1,340	3,897	9,754	4,046	9,411

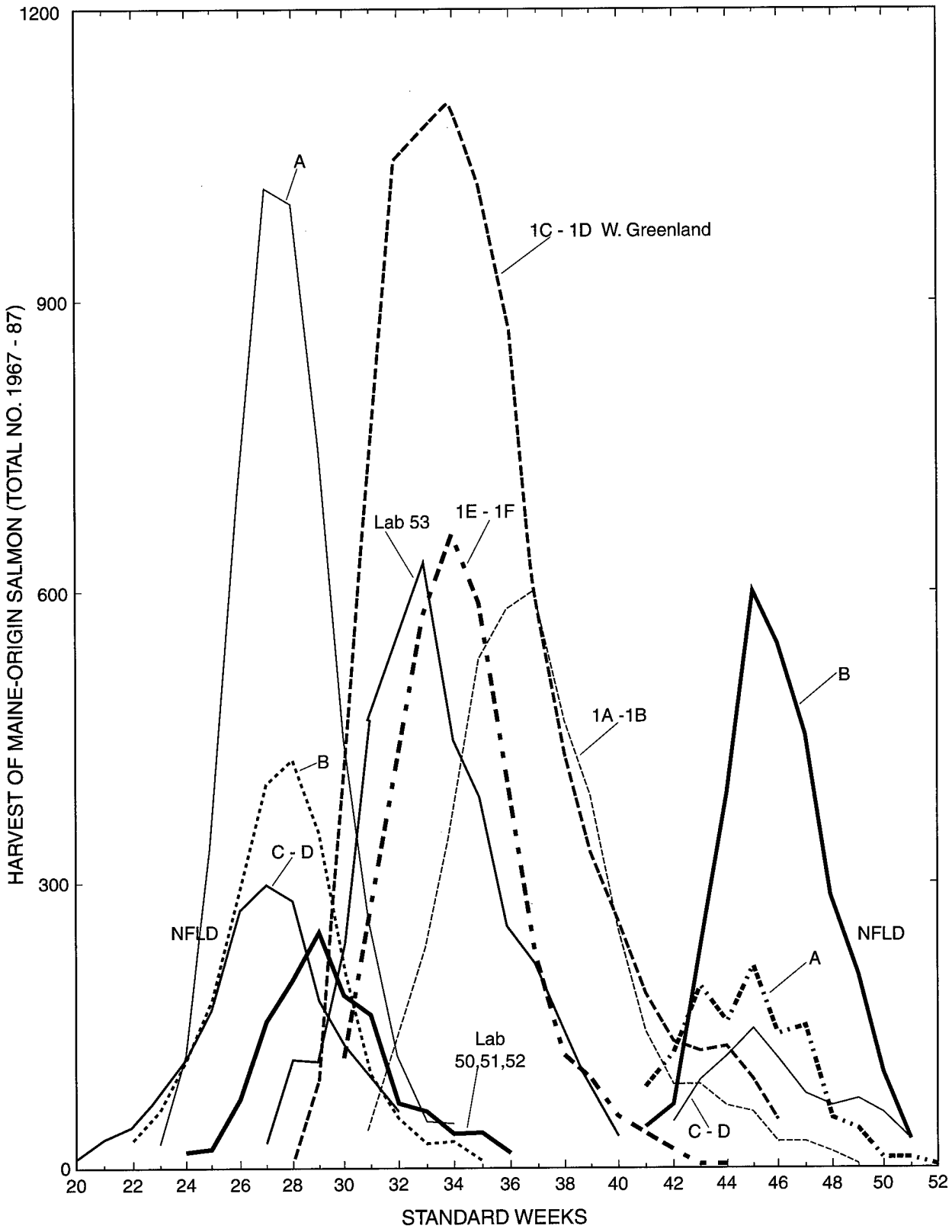

Figure 7. Harvest of Maine salmon by areas and weeks.

These salmon may also move to West Greenland, although it is possible that West Greenland salmon remain in offshore waters until water temperatures warm and then move straight north to Greenland without going to Newfoundland at all.

Another possible migration scenario is that when salmon reach the Newfoundland coast, they follow the coast north toward Davis Strait (Fig. 8) and only cross over to Greenland at high latitudes. Salmon tagged in northern Newfoundland by Canada have produced recaptures mainly from Labrador and the northeastern Gulf of St. Lawrence (Belding and Prefontaine 1961). Jensen (1980) indicated that in the tagging of salmon in the Labrador area in 1972, no salmon were recovered at West Greenland in the same season. This points to the possibility that immigration to West Greenland could be negligible after the fishing season has started. The catch-per-unit effort figures also correspond well with this assumption (Anderson et al. 1980). While the peak of the fishery on Maine-origin salmon in northern Labrador (Area 53) occurs on August 20 (Table 5), it also peaks at West Greenland on August 25. Atlantic salmon from Maine are also caught off West Greenland as early as mid July. The salmon fishery in Areas 1A and 1B (Fig. 7) reaches its peak in the middle of September and lasts through October.

Jensen (1980) assessed the distribution of salmon along the West Greenland coast that originated from North America and Europe. He found that the European salmon were distributed evenly throughout the entire fishing area and fishing season, while fish from North America were more prominent in the southern part of the fishing area and later in the season. Lear and Sandeman (1980), using scale characters, agreed that the percentage of North American salmon decreased with increasing altitude along the West Greenland coast. They also suggested that a discontinuity occurred (in 1972) between the West Greenland coast and the Labrador Sea, where the North American proportion increased more sharply with decreasing latitude. Relatively good catches of salmon have also occurred consistently in the mid Labrador Sea, about halfway between southern Labrador and southern Greenland in an area where salmon are also found in spring.

May (1973) reported that in late summer and autumn, Atlantic salmon were concentrated along the West Greenland coast but could be found as far as 48 to 64 km offshore. Since 1975, when fishing by non-Greenlandic vessels was halted, the fishery has mainly occurred very close to shore by vessels less than 9 m in length. Salmon are concentrated heavily at West Greenland at certain times and places. During 1985–87, the nominal catch for the first week of the fishery averaged 384 metric tons or 126,000 individuals. The entire catch quota can often be taken in a few weeks.

Salmon also move into the Irminger Sea off East Greenland. The recovery of tagged salmon from the East Greenland waters near Angmagssalik indicates a distance travelled, according to Meister (1984), of 2,847 statute miles from home waters in Maine. Exploratory fishing surveys in 1966 (Jensen 1967) and 1973–75 (Jensen and Lear 1980) off East Greenland point to a very wide but low density of fish in the area. Most of the fish found in the surveys were of European origin, but up to 21% of the fish caught were assumed to have originated from North America (Jensen and Lear 1980).

The fall fishery off northeast Newfoundland begins in early October as catches cease off Labrador and reach a peak in early November as the catches stop off West Greenland. The majority of catch in the fall fishery is taken in Area B (Fig. 5) as the fish are moving south. In spring most of the fish are caught in Area A as the fish are moving west. I assume that all of the Maine-origin salmon in Labrador are available to be caught at Newfoundland in Areas A-D in fall. Fish from West Greenland may migrate straight south and pass Newfoundland. The return journey for Maine-origin salmon from Greenland, as postulated by Meister (1984), is a direct route from Greenland across the Labrador Sea to the northeast coast of Newfoundland, then easterly as far as the Flemish Cap to overwinter.

Maine-origin salmon have also been captured in areas between Newfoundland and home waters during summer (Anonymous 1988). This is new information (Table 6) that is not yet available by standard week or statistical area. I assume that the one-sea-winter fish would have returned the following year as two-sea-winter fish because very few salmon return as grilse to Maine rivers. Before 1980, only about 5% of the run entering Maine rivers were grilse (Anonymous 1989b). According to Meister (1984), these one-sea-winter fish are moving at rates of less than 3 km per day, which supports the assumption that they would return the following year as two-sea-winter fish. I assume that they were caught in July, for purposes of calculations and were not available to any summer or fall fisheries. From 1967 to 1987, 64 salmon were estimated to have been caught in Quebec, 41 off Cape Breton Island, 591 in Nova Scotia, and 1,372 in the Bay of Fundy (Table 6).

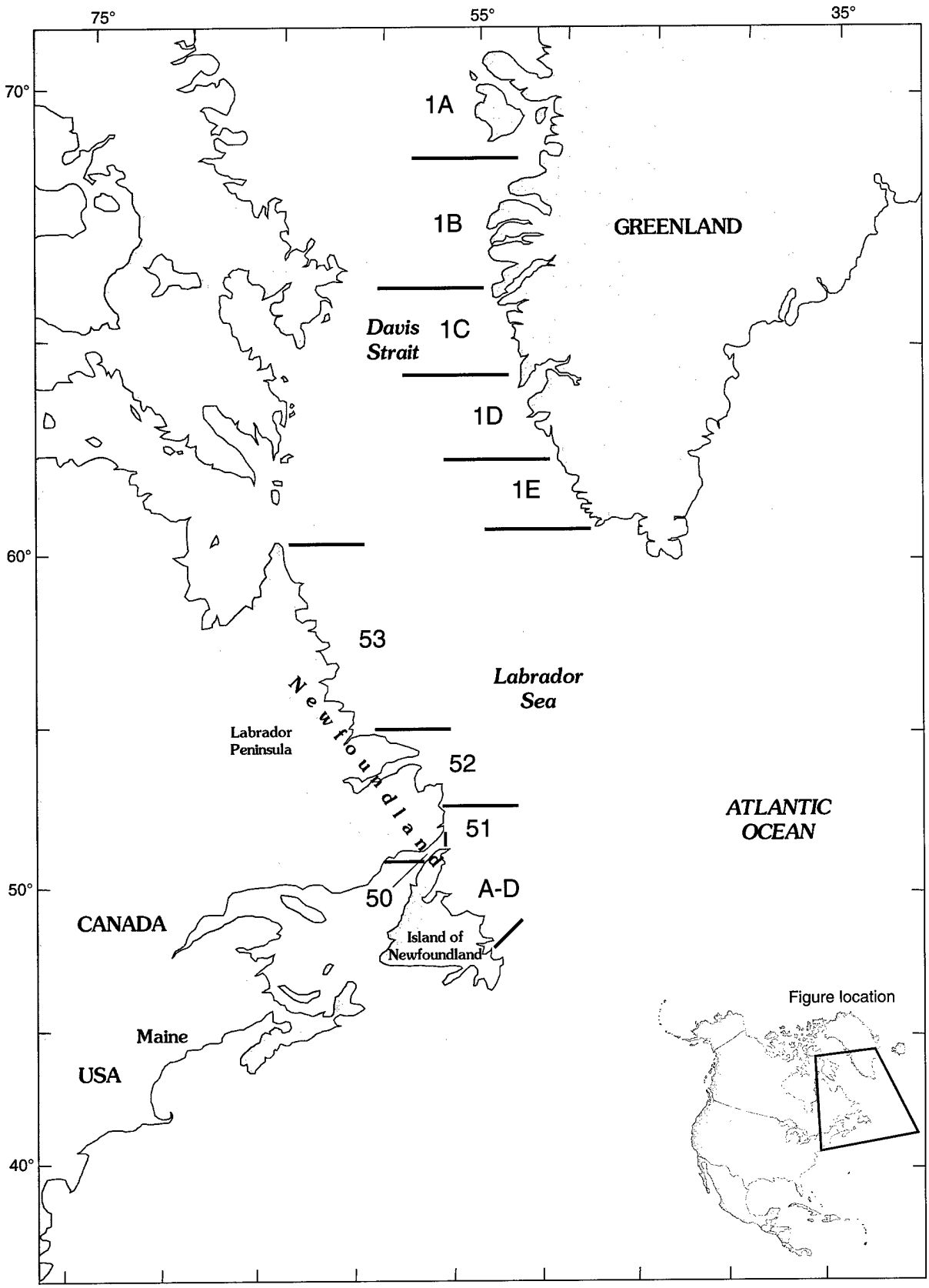

Figure 8. Statistical areas for reporting of catch and tag returns for West Greenland and Labrador.

Table 5. Harvest times of Maine-origin salmon in interception fisheries

Fishery area	Start of fishery standard		Peak of fishery standard		End of fishery standard	
	Week	Date	Week	Date	Week	Date
Newfoundland Area C, D	20	May 14–20	27.0	Jul 5	32	Aug 6–12
Newfoundland Area B	22	May 28–Jun 3	27.6	Jul 9	35	Aug 27–Sep 2
Newfoundland Area A	23	Jun 4–10	27.9	Jul 11	34	Aug 20–26
Labrador Areas 50, 51, 52	24	Jun 11–17	29.5	Jul 23	36	Sep 3–9
Labrador Area 53	27	July 2–8	33.4	Aug 20	40	Oct 1–7
West Greenland Area 1E, F	30	July 23–29	34.2	Aug 25	44	Oct 29–Nov 4
West Greenland Area 1C, D	28	Jul 9–15	35.0	Aug 30	46	Nov 12–18
West Greenland Area 1A, B	31	Jul 31–Aug 5	37.2	Sep 15	49	Dec 3–9
Newfoundland Area A	41	Oct 8–14	44.6	Nov 5	51	Dec 17–23
Newfoundland Area B	41	Oct 8–14	45.6	Nov 12	52	Dec 24-31
Newfoundland Areas C, D	42	Oct 15–21	45.8	Nov 13	51	Dec 17–23

Table 6. Harvest estimates of one-sea-winter Maine-origin salmon between Newfoundland and home waters

Recapture year Canada	Bay of Fundy		Nova Scotia		Cape Breton		Quebec		Total	
	Number of tags	Harvest	Number of tags	Harvest	Number of tags	Harvest	Number of tags	Harvest	Number of tags	Harvest
1967	2	13.0	1	6.5					3	19.5
1968	4	581.9	1	145.5					5	727.4
1969	1	98.3	1	98..3					2	196.6
1970	1	15.7	1	15.7					2	31.4
1971	2	14.0	1	7.0					3	21.0
1973	1	10.2							1	10.2
1974	3	24.4			1	8.1			4	32.5
1975	2	22.2							2	22.2
1976	10	329.1	2	65.8	1	32.9			13	427.8
1977	1	66.4							1	66.4
1978	1	82.9							1	82.9
1980	3	50.2	5	83.7			3	50.2	11	184.1
1981			1	31.8					1	31.8
1982	3	64.1	1	21.4					4	85.5
1983			1	76.2					1	76.2
1984			1	39.0					1	39.0
1987							1	13.3	1	13.3
Total	34		16		2		4	63.5	56	2,067.8

Three significant interception fisheries, therefore, can be described that harvest large quantities of U.S. fish (Fig. 9): the spring fishery on the north shore of Newfoundland (Statistical Areas A through D), the summer fishery at Labrador (Area 53) and West Greenland (mainly areas 1C, 1D, 1E, and 1F), and the fall fishery again on the Newfoundland northeast coast in Areas A-D. The recoveries in Labrador Areas 50, 51, and 52 and in Areas 1A and 1B of West Greenland constitute transitory fisheries. Atlantic salmon from Maine do not appear to stay in these areas long enough in any amount to attract a sizeable fishery. Table 5 indicates the start of these fisheries, when they peak, and when the last few fish are taken. The peak of the fishery is calculated as an average number over the years 1967–87 weighted by the number of fish harvested by week. Figure 9 reflects the smoothed combined harvest data given in Table 4. The three fisheries, spring, summer and fall, are well defined and are each important in the exploitation of Maine-origin Atlantic salmon.

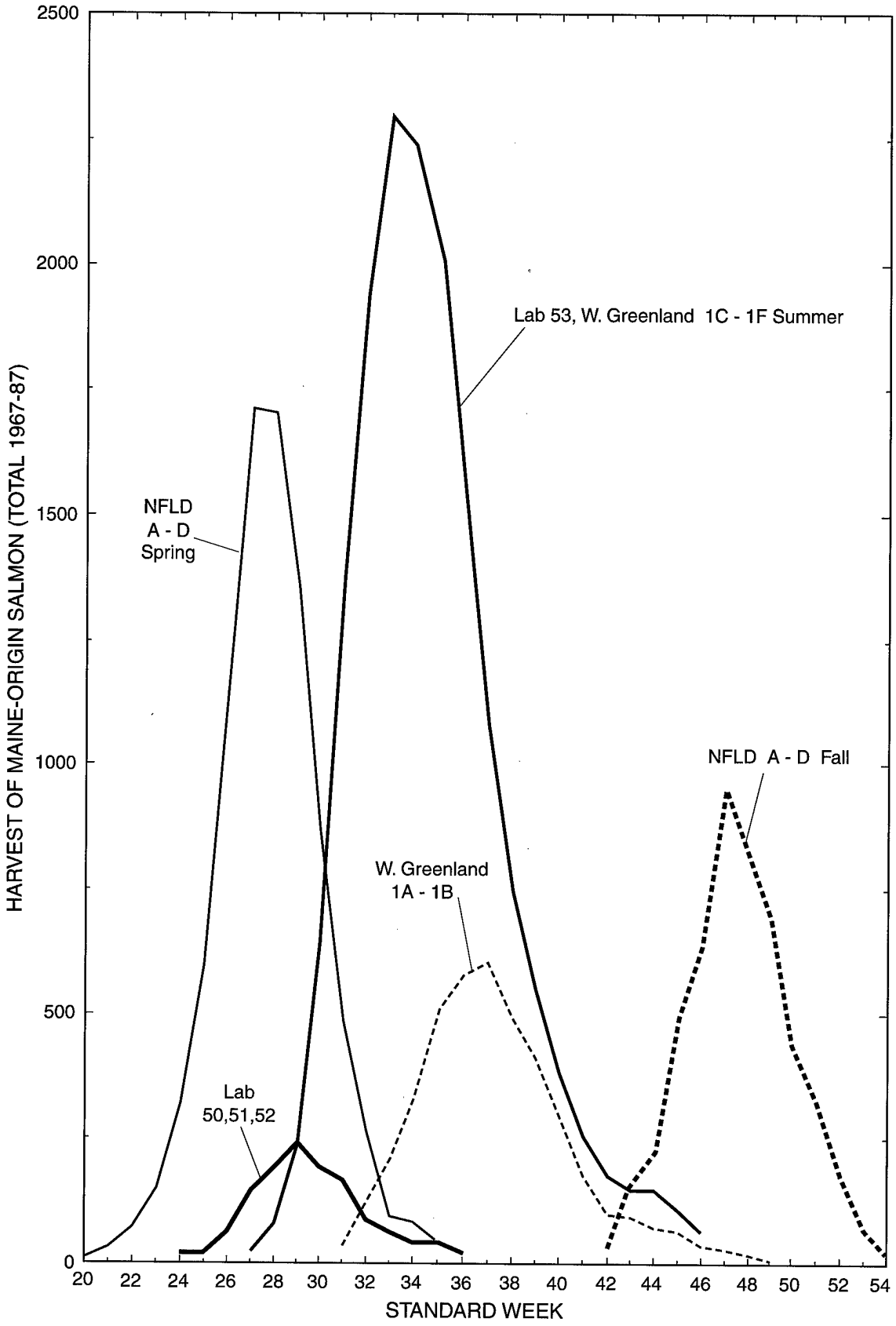

Figure 9. Harvest of one-sea-winter Maine-origin salmon by fisheries and standard weeks (smoothed).

Harvest of Salmon by Interception Fisheries

Ratio Harvest Method

The method for estimating harvests of one-sea-winter Maine-origin salmon from the Carlin tagging data was developed at the 1984 North American Study Group meeting held jointly by Canadian and American scientists (Anonymous 1985). The method expands the number of tag recoveries from fish tagged as smolts in the United States to total numbers of one-sea-winter U.S.-origin fish killed in a given fishery using the following equation:

$$\frac{\text{Harvest}}{\text{Tags recovered}} = \frac{\text{Run size at home}}{\text{Tags recovered at home}} \quad .$$

Solving for the harvest of one-sea-winter fish in year i gives

$$\text{Harvest} = \frac{\text{Tags recovered}}{\text{Ratio}_{i+1}} = \frac{T_i}{\text{Ratio}_{i+1}} \quad .$$

The ratio is the total number of tagged salmon in the smolt class that enter U.S. rivers in year $i+1$ to the total number of salmon of that smolt class entering U.S. rivers in year $i+1$. The parameters in the equation can be further adjusted to allow for nonreporting (R), loss of tags (L) by the fish between the fishery and when it returns to home waters a year or so later and noncatch fishing mortality (NC). The final equation is

$$H_i = \frac{T_i L}{R\,(1\text{-}NC)\,\text{Ratio}_{i+1}} \quad , \qquad (1)$$

where

L is the proportion of salmon that retain tags between the fishery in year i and returns to home waters in year $i+1$. This value was 0.9 for all fisheries;

NC is noncatch fishing mortality. This was 0.2 at West Greenland and 0.1 in Canada; and

R is reporting rate of those tags that were actually recovered. The reporting rates used by the ICES Working Group have been 0.9 for all years at Labrador, 0.7 for all years at Newfoundland, and 0.8 for years 1967–75 and 1983–88 at West Greenland. Values of 0.6, 0.6, and 0.5 were used for 1976–78, respectively, and values of 0.4, 0.5 and 0.6 were used for 1980–82.

Noncatch fishing mortality refers to mortalities associated with the act of fishing by a particular type of gear but that do not become part of the landings. These mortalities are predation, drop-out, haul-back, escapement, discard, and other, such as illegal or unreported local sales (Anonymous 1981). These estimates vary from fishery and from year to year and can be significant in some cases.

In 1984 the ICES Working Group (Anonymous 1985) decided to calculate the harvest of one-sea-winter Maine-origin salmon only because most of the tag recoveries were from the Maine stocks, no tag recoveries represented the Merrimack or Pawcatuck River stocks, and tag releases from the Connecticut River stock had a much lower return rate. In most years, adult returns to states in the United States, other than Maine, were negligible. The Working Group also decided to calculate the ratio to include all of the untagged salmon returning to Maine rivers. Complete return information (run counts, number of tags, etc.) was available for the Penobscot River, but run sizes were estimated for other rivers with unknown precision. Harvests in interception fisheries, therefore, were from all Maine rivers and not just fish that would have returned to a single river.

Basis of Reporting Rate Assumptions

The greatest uncertainty in the harvest equation is the assumed reporting rate. There are many examples of known recoveries of tags that were never returned. Estimates of reporting rates have been made for the West Greenland fishery by Jensen (1980) and Ritter (1985). Jensen was able to produce a reporting rate of 0.84 for 1972, which was the year of the ICES/ICNAF Tagging Experiment at West Greenland. Tags were recovered side by side by scientists aboard fishing vessels and by native fishermen so that direct comparisons could be made. This reporting rate of 0.84 is considered to be the maximum value because the presence of scientists in the area probably raised attention and responses to the tagging activities. Ritter (1985) assumed that the West Greenland proportion of the

total salmon tags recovered varied with the catch of North American salmon at Greenland. His analysis indicated that the reporting rate for tags recovered in the Greenland fishery during the 1980's was roughly one-fourth the rates for the fishery during the early and mid-1970's for Maine-origin salmon. Two-year running average estimates for 1980–81 and 1982–83 produced reporting rates of 0.26 and 0.05, respectively. Ritter suggested that the reporting rate in 1984 might be as low as 0.1. The Atlantic Salmon Working Group of ICES (Anonymous 1987) accepted the procedure as advocated by Ritter for West Greenland but did not accept these low estimates in the 1980's. The reporting rates that were used by the Working Group are given above. I used these rates in the harvest calculations by week and area in this paper to define migration and fisheries because these were already calculated by the Working Group and did not affect the conclusions concerning movements within a given year.

In my calculations of population size and exploitation rates, however, I used different rates for 1983 to 1988 for West Greenland. These are based on comparisons of harvest numbers from Carlin tags with those calculated by the proportional method, the scale circuli method, and the CWT calculations.

For at least 2 years (Anonymous 1988, and Anonymous 1989a) the ICES Salmon Working Group has estimated numbers of U.S. fish caught at West Greenland based on the number of one-sea-winter North American salmon of river age 1 in the West Greenland fishery, as indicated by the relative proportions of 1-year-old smolts produced by U.S. and Canadian hatcheries. This is known as the proportional harvest method. Wild salmon are of river age 2 and older from both sides of the Atlantic.

Another method of determining number of U.S. fish and West Greenland catches was used for the first time in 1989, which involved circuli spacing of scales from the smolts produced by the U.S. hatcheries. Tracking these fish from the samples taken a year later at Greenland provided a direct estimate of the catches of these hatchery fish.

In 1986, CWT's were placed in Atlantic salmon from Maine rivers (Table 2). Because the methodology to calculate catches of U.S. salmon at West Greenland for CWT's is the same as for Carlin tags, information on harvests from CWT's was not available until 1989. Recoveries of CWT's from smolts tagged in 1986 in Maine were made in 1987 in the interception fisheries for the first time, but home water recovery information for these tags was not available until the end of 1988 or early 1989. Only one harvest estimate (for 1987), therefore, has been calculated by this method.

The estimates of harvest at West Greenland from these three procedures, although based on several assumptions, are much greater than the harvest estimates of Maine-origin salmon made from Carlin tags. For 1987, the Carlin estimate of Maine-origin salmon caught at West Greenland was 2,152 salmon, compared with an estimate of 6,006 from the proportion method and 5,593 from the CWT method (Anonymous 1989a). For 1988, Carlin tag and CWT estimates are not yet available, but the proportional method and the scale circuli method gave estimates of 4,811 nad 5,087 fish (Anonymous 1989a), which are considerably higher than any previous harvest estimates at West Greenland.

The ICES Working Group felt that the discrepancies could be explained by errors in reporting rates and nondetection of tags. The reporting rate would have to be about 0.3, however, which is lower than any of those used by the Working Group but more in line with the reporting rates for recent years suggested by Ritter (1985). For this analysis, therefore, I used the values of reporting rates given in Anonymous (1987) and listed above for 1967 to 1982, but 0.5 for 1983 to 1987. I feel that 0.5 is closer to the true value than 0.8, but it is still a compromise until the ICES Working Group addresses the conflicting values of harvest numbers.

Harvest Estimates by Fishery and Area

The estimates of harvest are shown in Table 7 by areas and in Table 8 by fisheries. The spring fishery harvests an average of 491 one-sea-winter salmon from Maine every year (Table 8). The fall fishery at Newfoundland harvests 342 fish per year and the West Greenland fishery takes 1,882 fish per year. Harvests of salmon from northern Labrador are included in the West Greenland fishery in Table 8. Harvests in southern Labrador are not included in these fisheries. These harvests compare with catches in Maine of 470 per year (Table 7) and an average run size of 2,452. From 1967 to 1987, the harvests of Maine-origin salmon in Canadian waters were 2.5 times as great as the catches by anglers in Maine. Harvests in the West Greenland area were 3.3 times greater than those in Maine.

Table 7. Harvests and run size of one-sea-winter Maine-origin Atlantic salmon

	Harvests (number of salmon)								
	Newfoundland					West[a]			Run
Year	Area A–D	Area E–N	Labrador area 50–53	Other Canada	Total Canada	Greenland areas 1A–1F	East Greenland	Maine	size in Maine
1967	170	55	20	20	265	238		221	
1968	436			727	1,163			177	664
1969	197	98		197	492	581		121	634
1970	314	32	85	31	462	896		161	787
1971	245	7	65	21	338	2,625	55	136	637
1972	45	11	61		177	905		294	1,328
1973	122	60	56	10	248	1,318		272	1,378
1974	120	44	33	855	2,854	37	253	1,306	
1975	808	99	172	22	1,101	1,386		356	2,182
1976	1,679	165	614	428	2,886	1,685		198	1,220
1977	730	132	155	66	1,083	958		472	1,920
1978	83		258	83	424	1,175		780	3,853
1979[b]								364	1,773
1980	3,550	334	1,068	184	5,136	2,374		1,342	5,225
1981	764	64	371	32	1,231	2,005		1,139	4,725
1982	1,154	192	366	86	1,798	1,374		1,265	5,440
1983	1,296		534	76	1,906	840		348	1,773
1984	780	117	485	39	1,421	1,414		609	2,793
1985	1,672	134	516		2,322	2,426	179	557	4,319
1986	267	30	254		551	3,369	67	541	4,892
1987	372	53	163	13	601	3,443		256	2,115
1988									2,520
Total	15,342	1,703	5,290	2,068	24,400	31,866		9,682	51,484
Annual average	767	100	265	122	1,220	1,677		470	2,452

[a]Reporting rates for 1967 to 1982 as used by ICES Working Group. Rates for 1983–87 were 0.5.

[b]No fish were tagged in 1968.

Estimated Canadian catches of one-sea-winter Maine-origin salmon vary from 117 fish in 1972 to 5,136 fish in 1980 (Table 7). From 1967 to 1975, annual harvest estimates averaged about 560 fish, and corresponding run sizes returning to Maine from 1968 to 1976 averaged about 1,126 fish per year (Fig. 10). From 1976 to 1985 Canada harvested 2,023 fish per year as the corresponding run sizes returning to Maine doubled to an average of 3,670 for the same smolt classes. The estimated number of Maine-origin salmon taken in West Greenland fisheries varied from the low of 238 salmon in 1967 to the high of 3,443 in 1987 (Fig. 10). From 1967 to 1975, the West Greenland fishery harvested an average of 1,350 fish per year. Following the imposition of a catch quota in 1976 at West Greenland, the catches averaged about 1,583 U.S.-origin salmon per year through 1985 (Table 7). So, while Canada's catch of U.S. fish increased (by a factor of 3.6) as Maine runs improved (by a factor of 3.3), West Greenland's catch increased only slightly (17%). The catch quota

beginning in 1976 may have helped keep the catch of Maine-origin salmon to its previous level. In 1986 and 1987, however, the situation changed (Fig. 10), as Canada's catch decreased to 576 fish per year on the average or 25% of the run sizes returning to Maine, while West Greenland's catch increased to 3,046 fish per year or 1.4 times the average run size of salmon returning to Maine rivers.

A comparison of the harvests of the interception fisheries with the run sizes for the entire period (Fig. 10) indicates that the Canadian fisheries caught 47% as many Atlantic salmon as returned to Maine, while the West Greenland fishery caught 62% as many as returned to Maine. Populations of Atlantic salmon returning to Maine would have been 2.1 times as large as they were if these interceptions had not occurred and the fish did not die while migrating back to home waters to spawn. This illustrates the value of controlling these interceptions if the restoration program in the United States is to succeed.

Table 8. "First estimation" estimates of population size, harvests, and exploitation rate for three interception fisheries

	Newfoundland spring fishery			West Greenland summer fishery			Newfoundland fall fishery		
		Harvest			Harvest			Harvest	
Year	Population size	Nfld areas A–D	E_{sp}	Population size	Lab 53 areas 1A–1F	E_{sum}	Population size	Nfld areas A–D	E_{fall}
1967	1,052	64	0.06	998	258	0.26	822	122	0.15
1968	1,031	148	.14				962	291	.30
1969	1,463	98	.07	1,416	581	.41	926	98	.11
1970	1,796	282	.16	1,595	957	.60	703	33	.05
1971	3,877	98	.03	4,104	2,679	.65	1,545	147	.10
1972	2,130	45	.02	2,236	957	.43			
1973	2,594	87	.03	2,625	1,366	.52	1,406	33	.02
1974	5,264	237	.05	5,339	2,854	.53	2,704	405	.15
1975	3,322	459	.14	3,032	1,515	.50	1,632	344	.21
1976	5,555	1,505	.27	4,114	2,120	.51	2,198	178	.08
1977	5,467	655	.12	4,683	1,081	.23	4,124	73	.02
1978	3,072	83	.03	3,088	1,433	.46			
1980	11,103	2,905	.26	8,099	3,064	.38	5,584	609	.11
1981	8,116	275	.03	7,905	2,352	.30	6,217	492	.08
1982	4,400	933	.21	3,489	1,607	.46	2,084	217	.10
1983	5,171	727	.14	4,494	1,314	.29	3,509	565	.16
1984	6,625	402	.06	6,167	1,778	.29	4,923	378	.08
1985	8,876	186	.02	8,963	2,838	.32	6,656	1,493	.22
1986	5,497	269	.05	5,441	3,438	.63			
1987	5,986	370	.06	5,965	3,587	.60			
Unweighted average	4,620	491	.10	4,408	1,882	0.44	2,875	342	.12

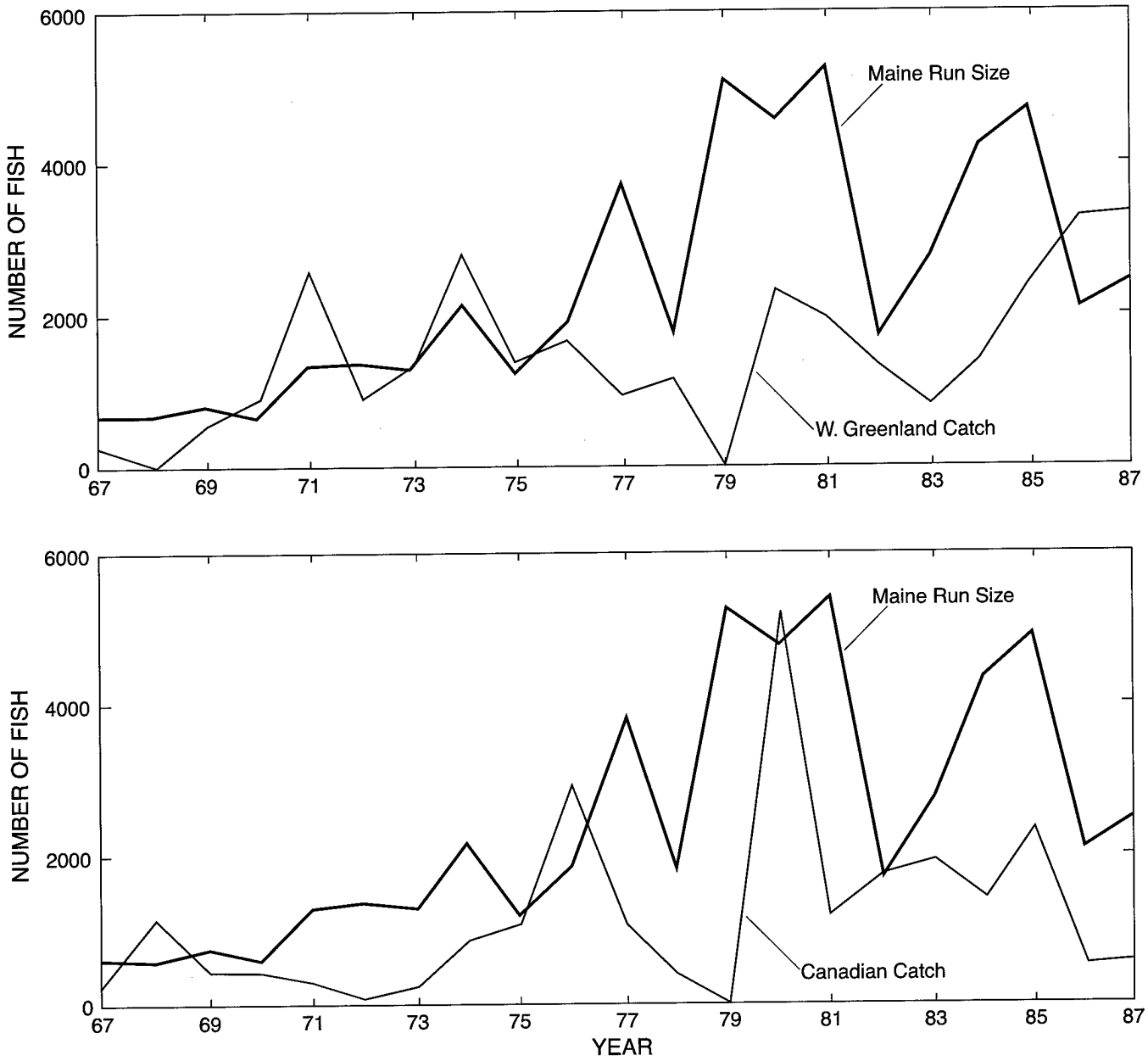

Figure 10. Comparison of catches by Canada and West Greenland and run size of Maine-origin salmon.

Exploitation Rates

An exploitation rate is simply the proportion of the population alive at the beginning of a period that is killed by fishing during the period; for example, catch divided by prefishery population. The prefishery population is estimated as the sum of the catches from the fishery and subsequent fisheries plus a proportion of the number of salmon returning to home waters, back-calculated in time to the beginning of the fishery by correcting for natural mortality. The calculations were performed with the level of natural mortality (M) equal to 0.00 per month or 0.0025 per week. Early estimates of M made in the ICES and ICES/ICNAF Working Groups varied from 0.016 to 0.64 per month. The 1974 ICNAF Working Group stated that the natural mortality between West Greenland and home waters probably lies in the range of 15–40% or an instantaneous rate of 0.016 to 0.051 per month over a 10-month period (Anonymous 1974). Horsted (1980), in reviewing the work of the ICNAF Working Groups, felt that the natural mortality rate between West Greenland and home waters probably was in the range of 23–47% or instantaneous rates of 0.026 to 0.064 per month. Anderson et al. (1980), however, assumed that natural mortality between Greenland and home water was negligible. Doubleday et al. (1979) used the method of Mathews and Buckley (1976), which assumes that natural mortality rates are between 0.005 and 0.01. The range of 0.01 to 0.02 per month was adopted in 1980 by the ICES Working Group (Anonymous 1981) and 0.01 has been generally used since.

Estimates of population size and exploitation were made for three fisheries: the spring fishery at Newfoundland, the summer fishery at West Greenland and Labrador, and the fall fishery at Newfoundland. The fall fishery at Newfoundland (Areas A–D) begins on October 4 (standard week 40) and lasts until the end of December (Table 4). The prefishery population (N_{fall}) was estimated from the following equation

$$N_{fall} = (0.95)\,(Run)\,e^{40.5(M)} + C_{fall}\,e^{5.5(M)} \quad , \quad (2)$$

where

N_{fall} is the abundance of one-sea-winter salmon in week 40;

Run is the number of fish returning to Maine in the following year on July 15;

M is the weekly instantaneous natural mortality rate of 0.0025; and

C_{fall} is the catch of one-sea-winter fish caught in the Newfoundland fishery of Areas A–D.

The exploitation rate is, then, calculated from

$$E_{fall} = \frac{C_{fall}}{N_{fall}} \quad .$$

These estimates are given in Table 8.

The catch of salmon in the Newfoundland fall fishery is assumed to have been taken at the peak of the fishery on November 12 (week 45.5) or about 5.5 weeks after the fishery began (Tables 4 and 5).

Salmon caught in areas between Newfoundland and home waters (Table 6) are assumed not to be available to the fall fishery. These fish were caught in June and July (Meister 1984) and were already on the way home. They probably were not available at Greenland or in the Labrador Sea either, as these salmon were caught during summer. The catches of these fish, listed as "Other Canada" in Table 7, averaged 122 per year when at least one tag was recovered over the period 1967 to 1987. With a monthly natural mortality rate of 0.01, 107 fish arrived home annually to spawn, on the average. This is about 5% of the average abundance (Table 7) of salmon returning to Maine. Therefore, only 95% (at most) of the run size is assumed to have been available to the fall fishery. This is a "first assumption" about the availability of the population to the fishing area that assumes a maximum availability to the inshore areas. The fisheries are very close to the shore, so unless the entire population migrates through the inshore areas, the population abundance is overestimated and the exploitation rates underestimated for a given fishery.

The prefishery abundance in the summer fishery at West Greenland - Labrador was calculated on July 5 (Week 27; Tables 4 and 5) and was estimated with the equation

$$N_{sum} = (0.80)(Run)e^{53.5(M)} + C_{sum}\,e^{7.5(M)} + C_{1AB}{}^{10.5(M)} + C_{fall}\,e^{18.5(M)} \quad , \quad (3)$$

where

C_{1AB} is the catch from West Greenland areas 1A and 1B, which begins on July 31, peaks of September 15 (Week 37.5), and ends during the first week of December; and

C_{sum} is the catch from the summer fishery at West Greenland and in the Labrador Sea.

The exploitation rate is then calculated from

$$\frac{C_{sum} + C_{1AB}}{N_{sum}} .$$

The catch of salmon from this summer fishery in northern Labrador (Area 53) and central (1C–1D) and southern Greenland (1E–1F) is assumed to have been taken at the peak of the fishery on August 25 (Week 34.5; Tables 4 and 5). The fishery in northern West Greenland (Areas 1A and 1B) is assumed to be a "transitional" fishery between the true summer fishery at Greenland and Labrador and the fall fishery at Newfoundland (Figs. 7 and 9). The exploitation levels associated with this fishery, however, are combined with the summer fishery at Greenland.

Only 80% of Maine salmon are assumed to be present at West Greenland. While this fishery is underway, Maine-origin salmon are also available in East Greenland and between Newfoundland and home waters. Jensen and Lear (1980) speculated that although the catch rates in the Irminger Sea were low compared with those at West Greenland, the number present could be high because the area is so large. Horsted (1980) stated, "there are, nevertheless, strong indications from other sources of evidence that a proportion of that stock does indeed occur outside the West Greenland area at the same time as the fishing at West Greenland takes place (Jensen 1967; May, 1973; Jensen and Lear 1980)." Horsted (1980), in his analysis, therefore assumed that some salmon do not visit West Greenland waters, and values of 10%, 20%, and 30% were chosen for his simulations. Jensen (1980), in fact, as mentioned above, noted that no salmon tagged in the Labrador area were recovered at West Greenland in the same season. Reddin (1988) also found salmon from North America and Europe in the Labrador Sea between Newfoundland and the southern tip of Greenland from spring to fall. In equation 3, therefore, I assumed that only 80% of the salmon returning to Maine waters were available to the West Greenland fishery.

Tag return information indicates that the spring fishery at Newfoundland begins about the latter part of May (Week 20 - May 17), peaks on July 9 (Week 27.5), and ends by the middle of August (Figs. 7 and 9 and Tables 4 and 5).

The prefishery population (N_{sp}) of the spring fishery at Newfoundland was estimated from this equation

$$N_{sp} = C_{sp}\, e^{7.5(M)} + 0.84\ [\text{Run}\, e^{60.5M} + C_{Lab}\, e^{9.5(M)} + C_{1A+B}\, e^{17.5(M)} + C_{sum}\, e^{14.5(M)} + C_{fall}\, e^{25.5(M)}] , \quad (4)$$

where

C_{sp} is the catch from the spring fishery, which peaks on July 9 (Week 27.5) (Tables 4 and 5 and Figs. 7 and 9); and

C_{Lab} is the catch in Labrador areas 50, 51, and 52 which is assumed to occur on July 23 (Week 29.5; Tables 4 and 5 and Figs. 7 and 9).

The fishery in southern Labrador is also assumed to be a "transitional" fishery between the spring fishery at Newfoundland and the summer fisheries at northern Labrador and at West Greenland. The exploitation rate at Newfoundland (Areas A–D is equal to

$$\frac{C_{sp}}{N_{sp}} .$$

In the spring of the year, salmon are also caught in Areas E–N around Newfoundland (Fig. 5). From 1967 to 1987, an average of 100 salmon were caught annually, with 93 of the 100 caught in the spring of the year. The peak catch occurs on July 8 (Week 27.5), which is very similar to the peak catch in Areas A–D (Week 27.6). These fish (93 annually) constitute about one-sixth of the total number caught annually in the Newfoundland fishery (584), but they cannot be ignored because they were caught at the same time as salmon in Areas A–D or Labrador fishery. Thus some proportion of the entire population is also not available in Areas A–D. If we assume that the exploitation rates are about the same in Areas E–N as they are in areas A–D, then we can assume that about one-sixth (about 16%) of the population is also not available in Areas

A–D. In equation 4, therefore, the major part of the population is reduced by 16%. The catch, of course, was fully available.

In all of the above calculations, I reduced the population availability when evidence indicated that it was warranted. This does not mean that the remainder of the populations were, in fact, fully available to the specific fisheries, although that is the basis of my "first assumption." While information is lacking to further reduce availability in the fisheries, the diverse migrations indicate that not all salmon are readily available to the inshore fisheries. Therefore, the present exploitation rates are minimum values.

The population sizes, catches, and estimates of exploitation under the above assumptions of migration and population availability are given in Table 8. The spring fishery catches about 10% of the Maine salmon population. The catch of one-sea-winter Maine-origin salmon in southern Labrador has been ignored in this estimate of exploitation rate except in the calculation of population size. The catch in this area has averaged only 70 to 80 fish per year, but in 1980, 352 salmon were taken. If we combine these catches with those from Newfoundland Areas A–D, the average exploitation rate becomes 0.11, or only 1% larger. The big harvest, in terms of total numbers caught and proportion taken, occurs in northern Labrador and at West Greenland in late August, where nearly half (44%) of the population is harvested. The fall fishery off Newfoundland takes its share also (12%) as the one-sea-winter fish move south to overwinter and return home the following spring.

If we consider other options of population availability, the exploitation rate estimates increase. As mentioned above, some evidence indicates that salmon going to northern Labrador do not go to West Greenland. If we assume that the exploitation rate in northern Labrador (Area 53) is 0.1 or 0.2, we can calculate a population size from the catch data and subtract it from the West Greenland population. The exploitation rate of 0.1 is apparently too low because this creates such a large population size in northern Labrador that, upon subtracting it from the total population in the Labrador–West Greenland area, in 5 years out of 19, the catch at West Greenland (Areas 1A–1F) was greater than the calculated population. (The exploitation rate for the remaining years averaged 0.58). If we assume that the exploitation rate in the northern Labrador area is 0.2 and subtract that population from the West Greenland area, the catch at West Greenland (Areas 1A to 1F) produces an exploitation rate (on the average) of 0.52.

Another migration assumption that could be explored is that only about half of the population that overwinters east of Newfoundland as post-smolts goes to Newfoundland in the spring and then into northern Labrador. The other half goes to West and East Greenland. After these summer fisheries only the northern Labrador population would be available to the fall fishery at Newfoundland, whereas the Greenland population of Maine-origin would go directly south and bypass Newfoundland. Estimates of exploitation rates under these assumptions would be between 0.5 and 1.0 for West Greenland, while the exploitation rate for northern Labrador would be less than 0.2.

Regardless of the several possible assumptions about migrations, the exploitation rate at West Greenland is greater than that in the other two fisheries; it is very high and probably greater than 0.5. The determining parameter is the reporting rate. With the present estimates of reporting rates at West Greenland, the total catches from all fisheries produce an annual average exploitation rate of 0.51. This rate is calculated by comparing the total harvests in the interception fisheries with the populations of salmon corrected for natural mortality and catches. All catches are assumed to have been caught during week 34 (late August), and the prefished population occurs on June 1.

If the CWT information, proportional analyses, and scale circuli estimates of harvest are more correct than the harvest estimates from Carlin tags, then the reporting rate at West Greenland is closer to 0.3 in recent years. This would put the estimates of exploitation at West Greenland at about 0.7 or greater which is much larger than estimates in earlier years. The 1978 and 1980 Working Groups (Anonymous 1981) reported that an average exploitation rate of 0.5 to 0.6 over the period 1970 to 1977 would be consistent with their analysis. Other early estimates of exploitation rates were made by Jensen (1980), Horsted (1980), and Andersen et al. (1980) based on the 1972 International Tagging Program Data. They concluded that the exploitation rate at West Greenland was about 0.30 to 0.35 (Horsted) and 0.33 (Jensen 1980; Andersen et al.) My estimates for 1972 were 0.43 for West Greenland (Table 8) and 0.46 and 0.53 if varying amounts of Labrador fish were not available to the West Greenland fishery.

Management Efforts

The success of the restoration effort in New England is clearly depending, to a large degree, on the level of harvest of U.S.-origin salmon in foreign fisheries. Within NASCO, regulations have been adopted by Canada and Greenland to reduce interceptions of these fish. In 1984 a quota level of 870 t was accepted, which was a reduction of 27% from the level of 1,190 t that had been in force for the previous 8 years (Fig. 11). Greenland then agreed to a slightly reduced quota of 850 t for the 1986 and 1987 fishing seasons. For 1988, 1989, and 1990 West Greenland agreed to an annual average quota of 840 t which should not be exceeded by 10% in any 1 year, and the total for 3 years could not exceed 2,520 t.

In 1984 the United States suggested to Canada and West Greenland that a reduction, shared equally, be made in their commercial catches to 1,700 t for Canada and 922 t for West Greenland. According to catch histories, a further breakdown by area could be 356 t for Labrador, 938 t for Newfoundland, and 422 t for Areas A through F. In 1988 the United States again recommended a catch quota of 416 t just for Areas A and B. In 1989 Canada announced that the interception of migratory salmon needed to be further addressed and introduced the concept of an "allowance" in the Newfoundland and Labrador fisheries. The allowance for Statistical Areas A and B was 440 t. Catches for Areas A and B for 1986, 1987, and 1988 were 394, 552, and 276 t, respectively (Anonymous 1988).

Canada has used areal and seasonal closures of various fisheries as a means of regulating interceptions instead. Beginning in 1984, all areas were closed until June 4. Area J (Fig. 5) was closed for certain periods. These two closures accounted for a 2.6% reduction in the interceptions of U.S. fish by Canada. In 1985 the Nova Scotia and New Brunswick commercial fisheries were closed, which had accounted for about 9% of the catches of U.S. salmon (Anonymous (1985). Canada closed the entire commercial salmon fishery after October 15 in 1986, which previously had taken 29% of Canada's interceptions of U.S. salmon. This is the fall fishery described previously.

In 1986 Canada initiated a mandatory tagging program of all commercially harvested fish in 1986 and began a buy-back program of commercial salmon licenses. Licensed fishing effort, expressed as gear units (where one unit is equal to 50 fathoms of gear), has declined steadily since its maximum level in 1975. In that year 25,181 units of gear were utilized. Various restrictive licensing policies by Canada reduced this number of gear units to 19,705 by 1983 (Anonymous 1988). In 1984–85 Canada's new buy-back program immediately caused additional reductions in all part-time fishermen and, through a voluntary program in 1984, some full-time fishermen. As a result, the number of gear units in use was reduced to a little over 13,000 by 1988. This is a 48% reduction in number of gear units from 1975 to 1988 and a 34% reduction from 1983 to 1988 when the buy-back program was in effect. Scientists have been unable, however, to relate this reduction in gear units to effective reductions in fishing mortality because much of the gear that was bought back was not being fished or was used by part-timers who were not as effective as full-time fishermen. The best estimates indicate that effective fishing effort may have been reduced by as much as 19%, but this estimate is very weak.

In 1984 Canada introduced its first 5-year salmon plan, which restricted fisheries at the mouths of rivers and within rivers to improve in-river survival and to reach the spawning biomass targets. For the previous 2 years, the number of multisea-winter spawners in index rivers in Canada had only met 32% of the spawning requirements (Anonymous 1988). From 1984 to 1987 the in-river survival improved from 30% to 75%, and these rivers met 78% of the targets. The numbers of multisea-winter fish returning to the mouths of the rivers did not increase, but the numbers of grilse did. Grilse are not taken in distant interception fisheries. Even with continued in-river restrictions on recreational fishing, an increase in returns of multisea-winter fish to the mouths of the index rivers of about 28% is needed to achieve the spawning targets set by Canada.

Acknowledgments

I thank D. Newton for typing this manuscript and B. Figuerido for drafting the figures. The Atlantic Sea-Run Salmon Commission in Maine had the foresight in 1966 to begin a series of tagging experiments that has produced more knowledge concerning Atlantic salmon migrations and exploitation rates than any other salmon study in the North Atlantic; we all thank them.

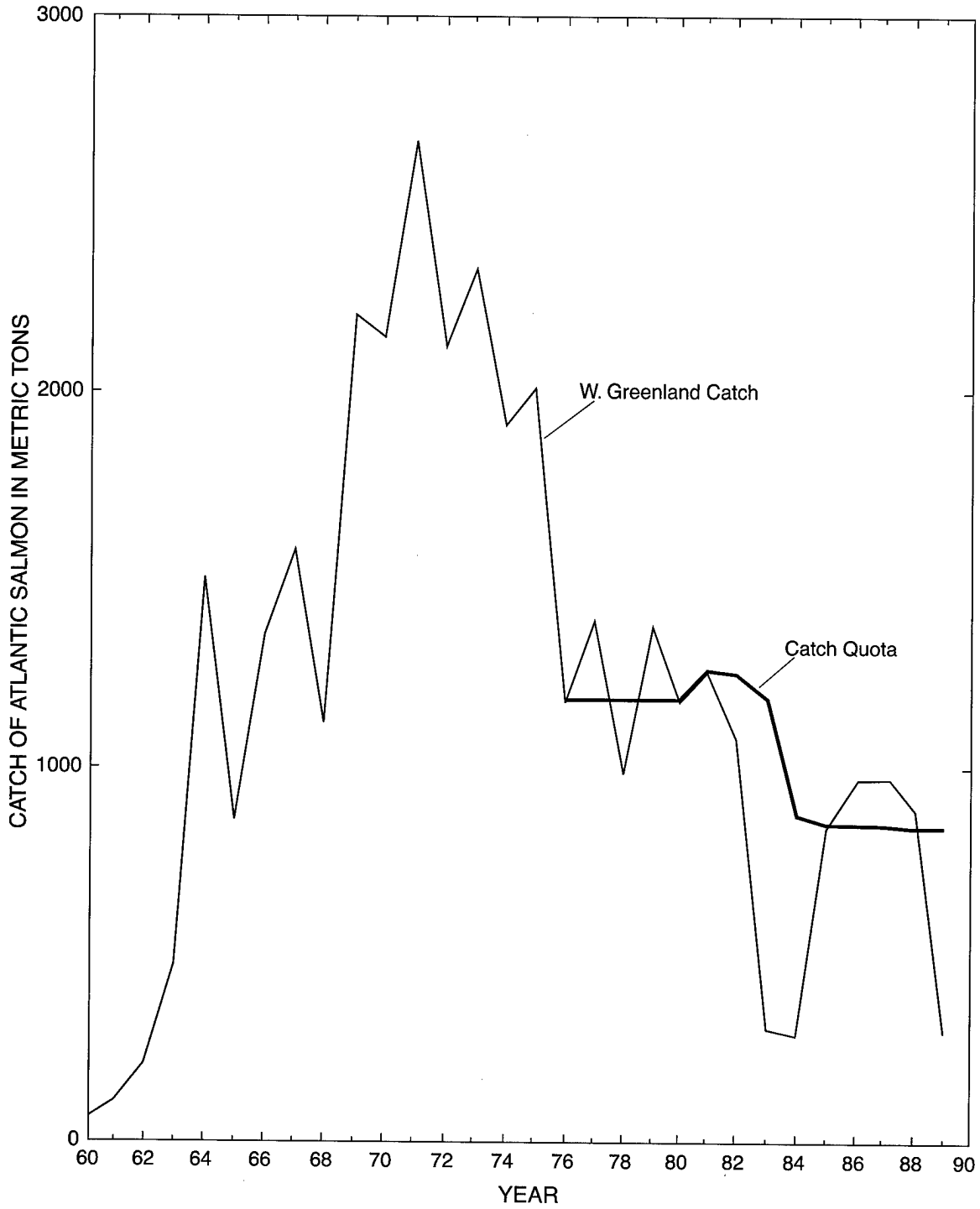

Figure 11. Total catch of Atlantic salmon at West Greenland and catch quota restrictions.

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Atlantic Salmon Genetic Structure in Connection With the Preservation and Exploitation of Salmon Stocks in the Union of Soviet Socialist Republics

by

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Abstract. Data are provided on intra- and inter-population genetic structures of Atlantic salmon (*Salmo salar* L.) from the rivers of the Barents, White, and Baltic Sea basins in the Union of Soviet Socialist Republics. A hypothesis about how salmon settled in this region is proposed. The influence of donor material transportation on genetic variation of artificially formed populations is shown. The material is discussed in connection with the protection, reproduction, and exploitation of Atlantic salmon stocks.

In the Union of Soviet Socialist Republics (U.S.S.R.) Atlantic salmon (*Salmo salar* L.) inhabit the rivers flowing into the Baltic, White, and Barents Seas, Lake Ladoga and Lake Onega, and some other large lakes. Their number have been greatly reduced for the last 4 to 5 decades owing to rafting, hydrobuilding, pollution, poaching, and other anthropogenic factors. Some populations have been extirpated. However, natural reproduction of Atlantic salmon still exists in 120 to 140 rivers, and in some other rivers, such as the Pechora, Varzuga, Ponoy, and Iokanga, the fishing industry preserves its economic importance.

The ecological diversity of the Atlantic salmon in Soviet rivers has been studied thoroughly; however, its genetic variation has not been investigated. Thus several years ago we started investigating the population and genetic structures of Atlantic salmon from the rivers of Europe north of the U.S.S.R. In this paper we present the results of our investigation, which was carried out according to the following objectives (Kazakov 1989, 1990; Titov 1990; Titov et al, 1990):

- study the general genetic divergency of the Atlantic salmon in Soviet rivers,
- study the special features of salmon intrapopulation genetic structure in the Pechora River, the largest salmon river in the world, and
- study the influence of fishery management on genetic variation in Atlantic salmon.

Methods

We studied Atlantic salmon from the rivers of northern Europe (Fig. 1). The material was gathered, as a rule, in the course of 2 to 4 years in every river (or every hatchery). The distribution of allele frequencies at six polymorphic loci with a certain genetic determination (Aat-2, Sdh-1, Idh-3, Me-2, Est-D, Px-2) was examined to estimate the genetic heterogeneity of the population.

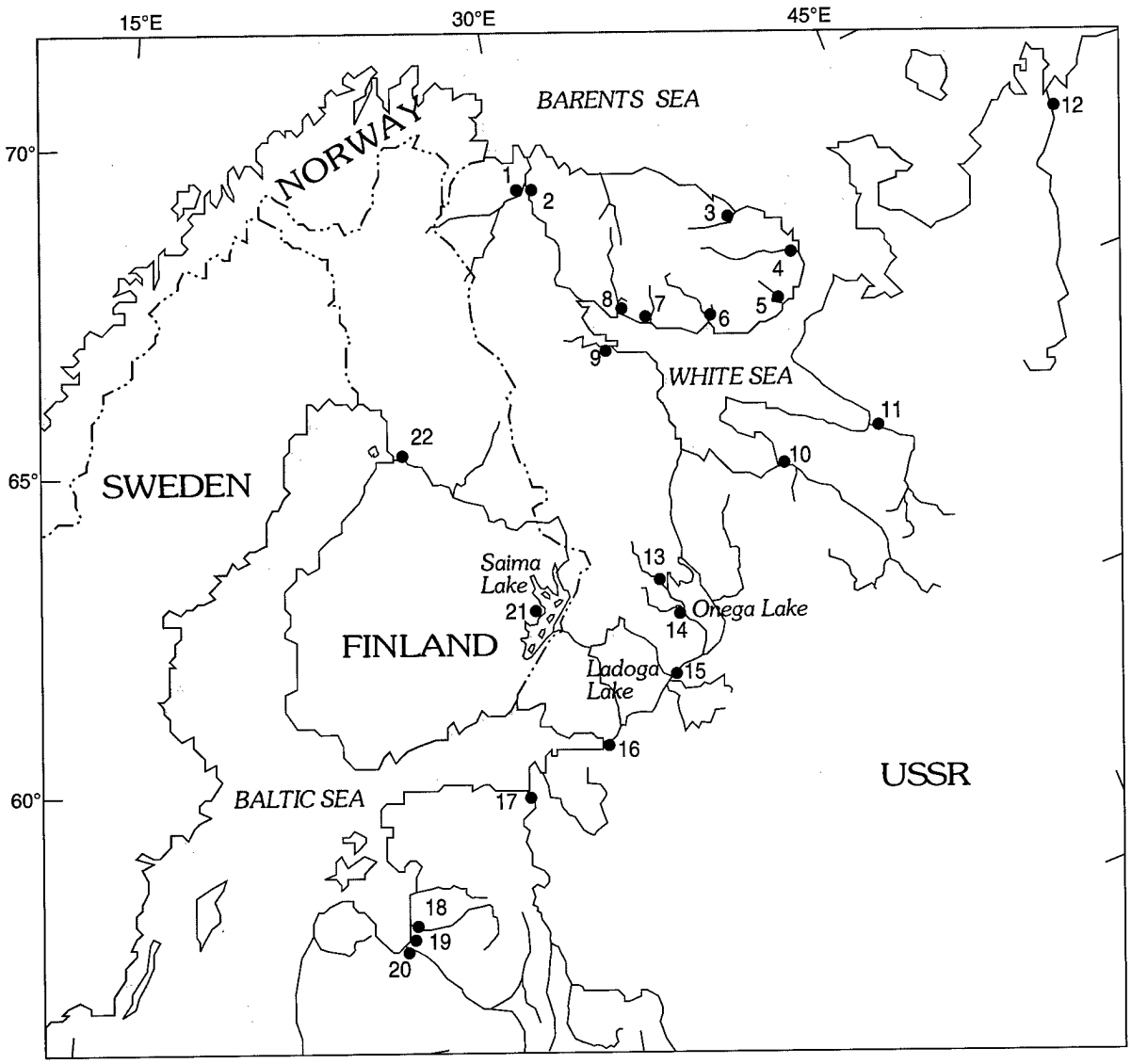

Figure 1. Collection sites.

Results and Discussion

Interpopulation Genetic Variation

All of the populations differ genetically from each other. They are divided into two clasters (Fig. 2), one of which comprises populations from the river basins of the White and Barents Seas and the other populations from the Baltic Sea.

While analyzing population divergence of allele frequencies at some loci, a certain regularity was discovered, which made it possible to come to a hypothesis about how Atlantic salmon settled in northern European waters.

The peculiarities of the distribution of allele frequencies at loci Est-D, Px-2, and Idh-3 can be taken as an example. As shown in Fig. 3, the fast allele at the Px locus in the populations of the Baltic Sea basin is either absent or its frequency is extremely low; 0.005–0.03. The same is true for the salmon from two other big hydrographic systems of the White (the Onega River) and Barents (the Pechora River) Seas. Unlike this, the allele frequency in most rivers of the Kola Peninsula is much higher, up to 0.09–0.13. A salmon population with the same allele frequency was found in a small river, the Solza, flowing into the White Sea between the Onega and Pechora Rivers.

The locations of populations based on the allele frequencies at the Est-D locus are much alike (Fig. 4). The Est-D locus is monomorphic in all of the populations of the Baltic Sea basin and in the Onega and Pechora River populations as well. In the salmon populations of the Kola Peninsula rivers and the Solza River the Est-D locus is polymorphic, the frequency of the slow allele ranging from 0.11–0.12 to 0.51.

The locations of populations based in the Idh locus portray the same principle (Fig. 5). In the rivers of the Gulf of Finland and Gulf of Riga (the Baltic Sea) the fast allele frequency at this locus is as low as 0.04–0.05 or it is monomorphic.

The Idh locus is also monomorphic in the populations from the Bothnian Bay, central Baltic, and North Sea rivers (our data are based on research information), and Lakes Saima, Ladoga, and Onega. The frequency of the fast allele at the Idh locus of the salmon populations from the Pechora and Onega Rivers is the same as that from the rivers of the Baltic Sea basin. However, the salmon population of the Solza River differs from those of the Pechora and Onega Rivers at this locus (0.13). But there is similarity between the Solza River salmon and the salmon population of Kola peninsula (0.07–0.45).

We think the patterns are connected with the peculiarities of salmon movement in the rivers of northern Europe after the retreat of the last glacier 5,000 to 12,000 years ago. The connections between the populations changed to a certain extent due to the subsequent evolution, but some of the most typical connections are preserved and can be seen when studying the genetic markers. Our explanation for these links takes into account the geological past of the region and the ways nearby reservoirs are connected.

The lakes that the freshwater salmon inhabit (Saima, Ladoga, Onega, etc.) belonged to the reservoir that was in the place of the Baltic Sea (Kvasov 1975) and still belong to this sea basin hydrographically (Fig. 6). Based on geological data the trend of their isolation ranges from 11,000 (Lake Onega) to 6,000 years (Lake Saima). Thus the genetic relation between the salmon from these lakes and the salmon from the Baltic Sea rivers is clear. The upper waters of the Pechora and Onega Rivers are south of 60° north latitude, and during the glacial period they were connected with the Baltic Sea through numerous reservoirs. The general patterns of the forming ichthyofauna in this region revealed the connections between these rivers and the Baltic Sea basin (Kudersky 1987). Lindberg (1955, 1972) suggested the possibility of fish settling through the upper waters during the period of global glaciation.

We hypothesize that the settlement of the Pechora and Onega Rivers occurred through the upper waters, and while the glacier was receding the salmon dispersed to other parts of these hydrographic systems, including the Barents and White Sea basins.

The salmon could disperse down the Kola Peninsula rivers from the Barents Sea area. Using the former water system (the Kola and Niva Rivers, Lake Imandra, and other reservoirs) the salmon could easily reach the southeastern coast, which accounts for the genetic similarity of the populations. From this waterway, salmon could go into small rivers of the nearby opposite coast of the White Sea (e.g., the Solza), which could not have been settled by salmon from the Baltic Sea. But the salmon were not likely to go this way to the Pechora and Onega Rivers at that time because of the ice jams, which existed for a long time in the most narrow part of the White Sea ("throat") and the part of the Barents Sea adjoining the mouth of the Pechora River.

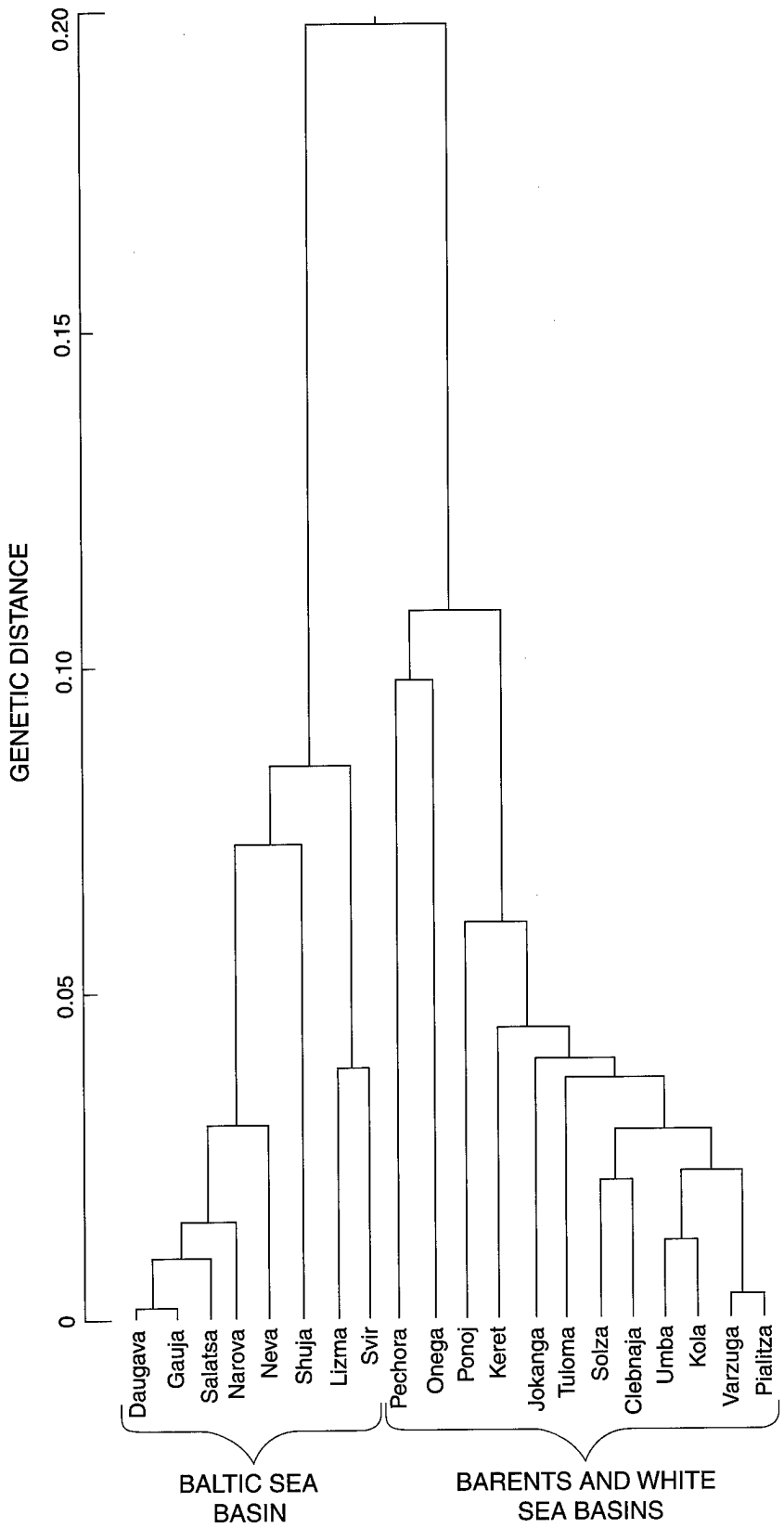

Figure 2. Dendrogram of genetic divergence in the examined populations.

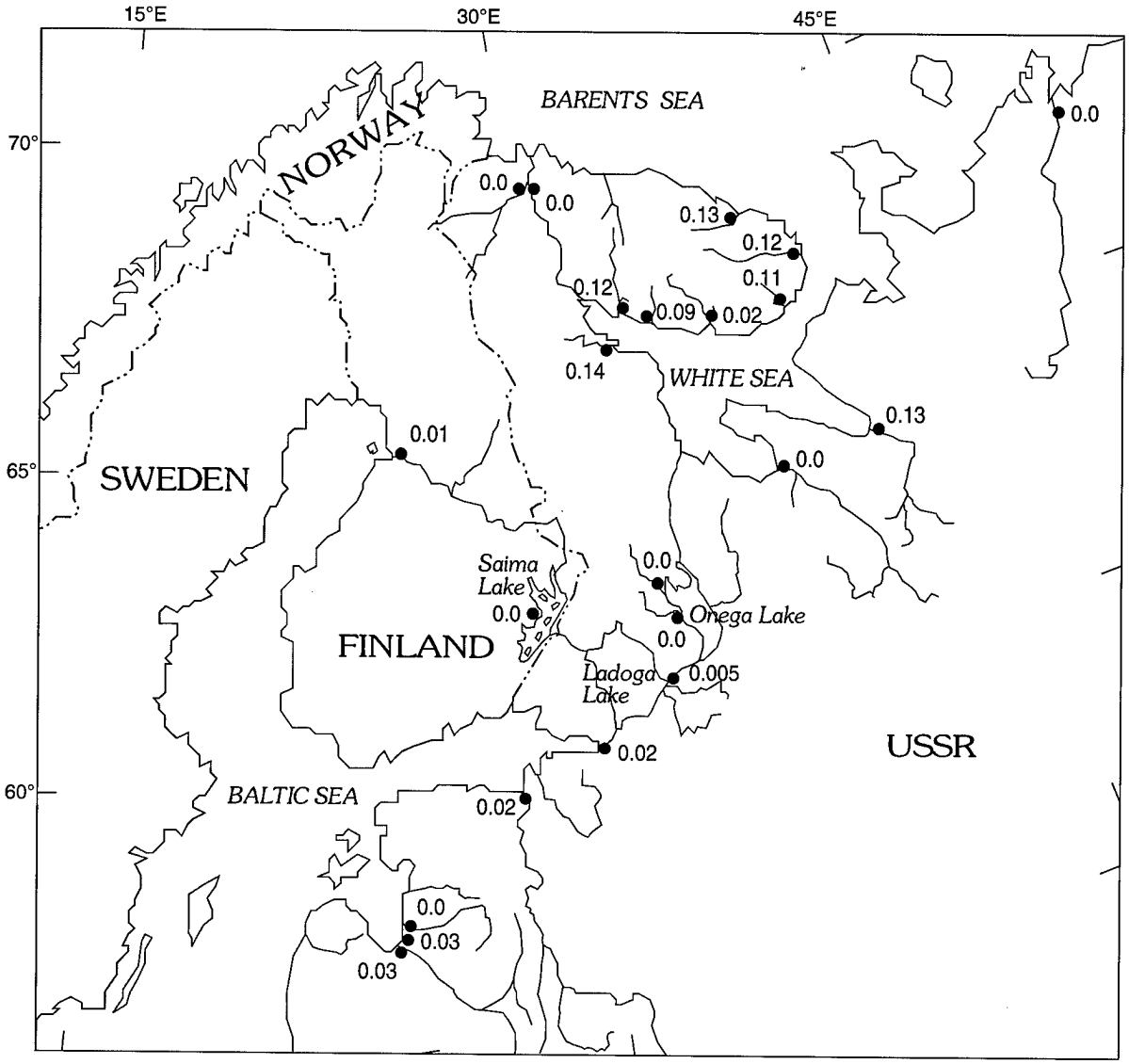

Figure 3. Allele frequencies at the Px-2 locus.

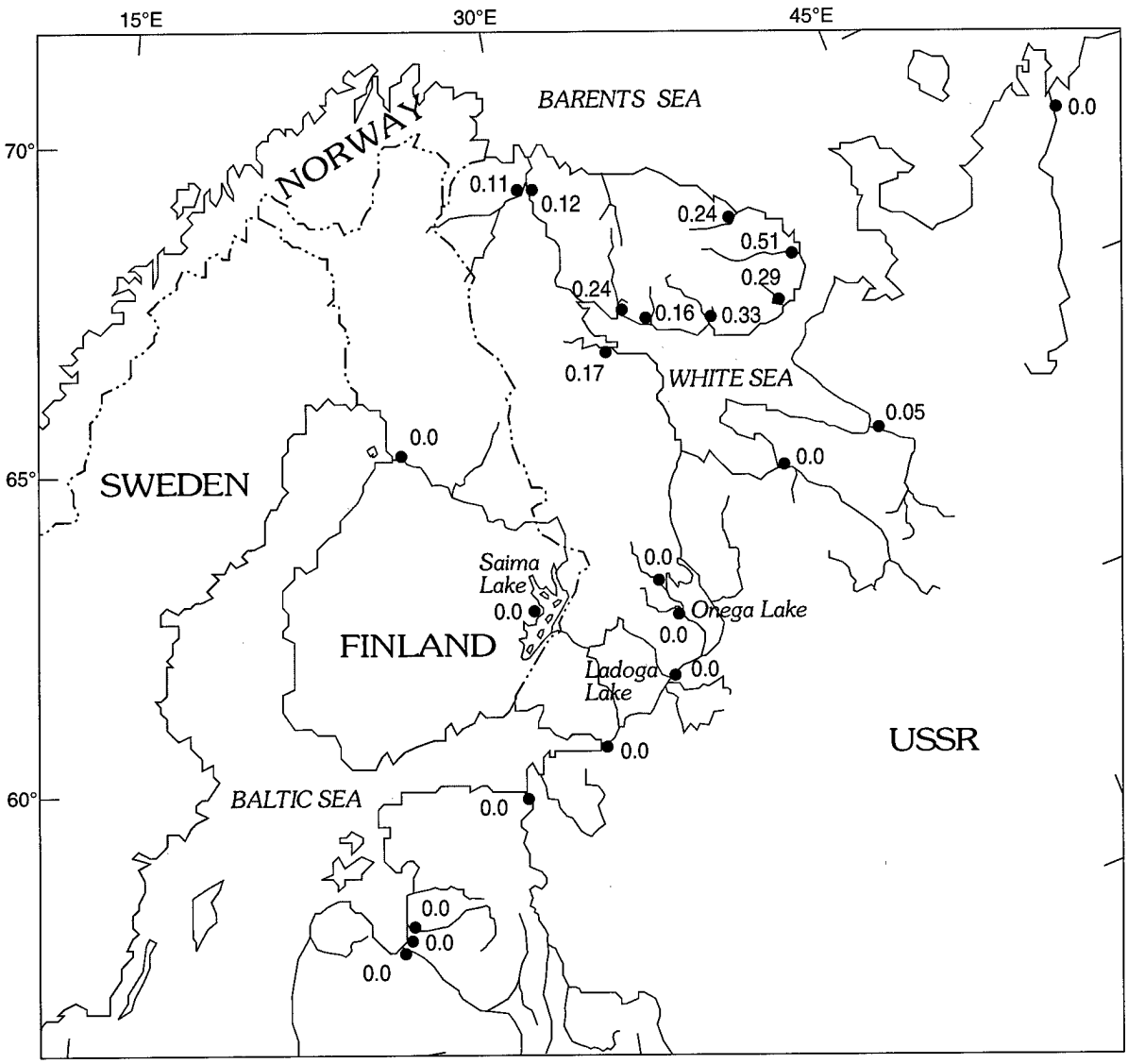

Figure 4. Allele frequencies at the Est-D locus.

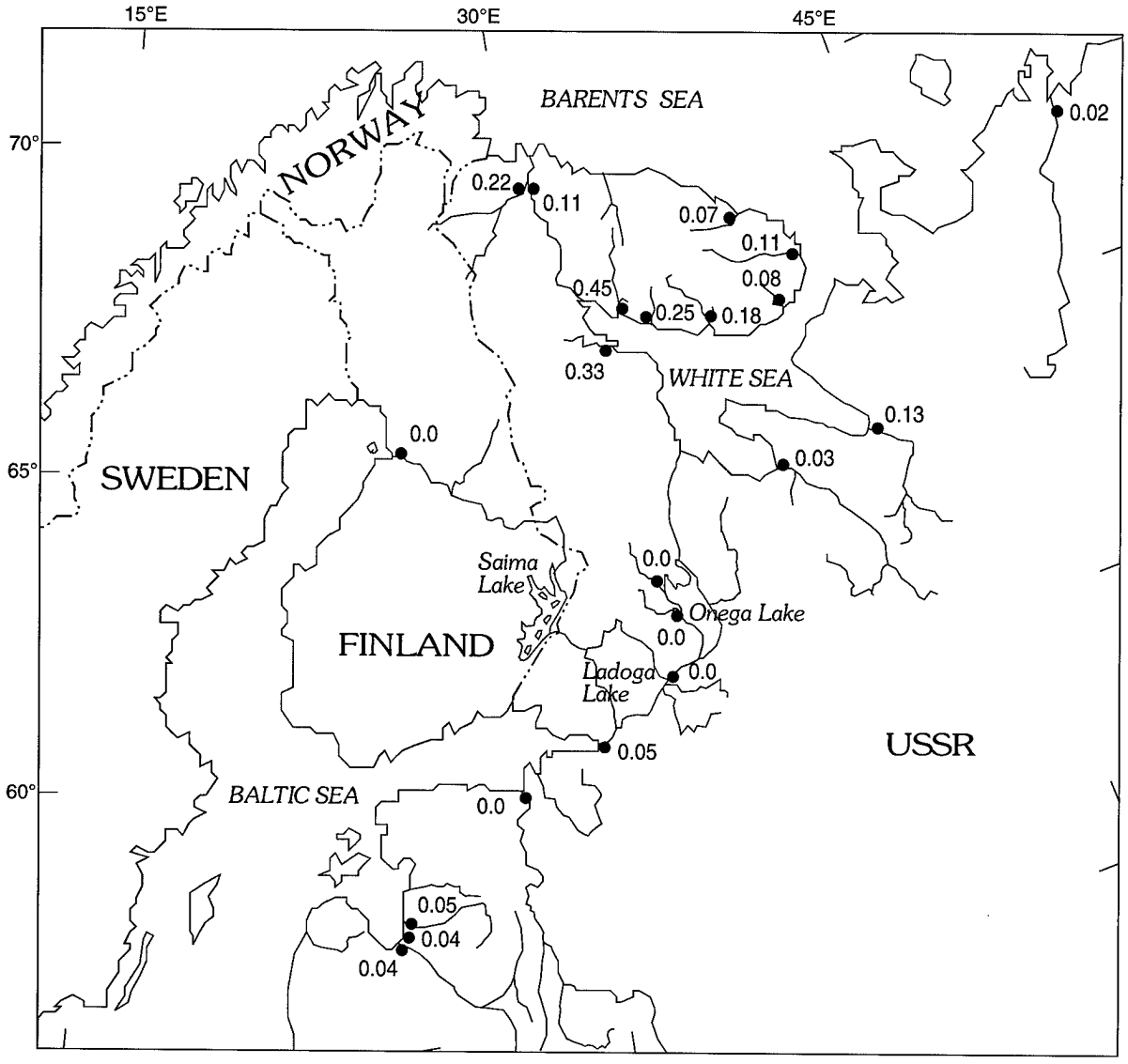

Figure 5. Allele frequencies at the Idh-3 locus.

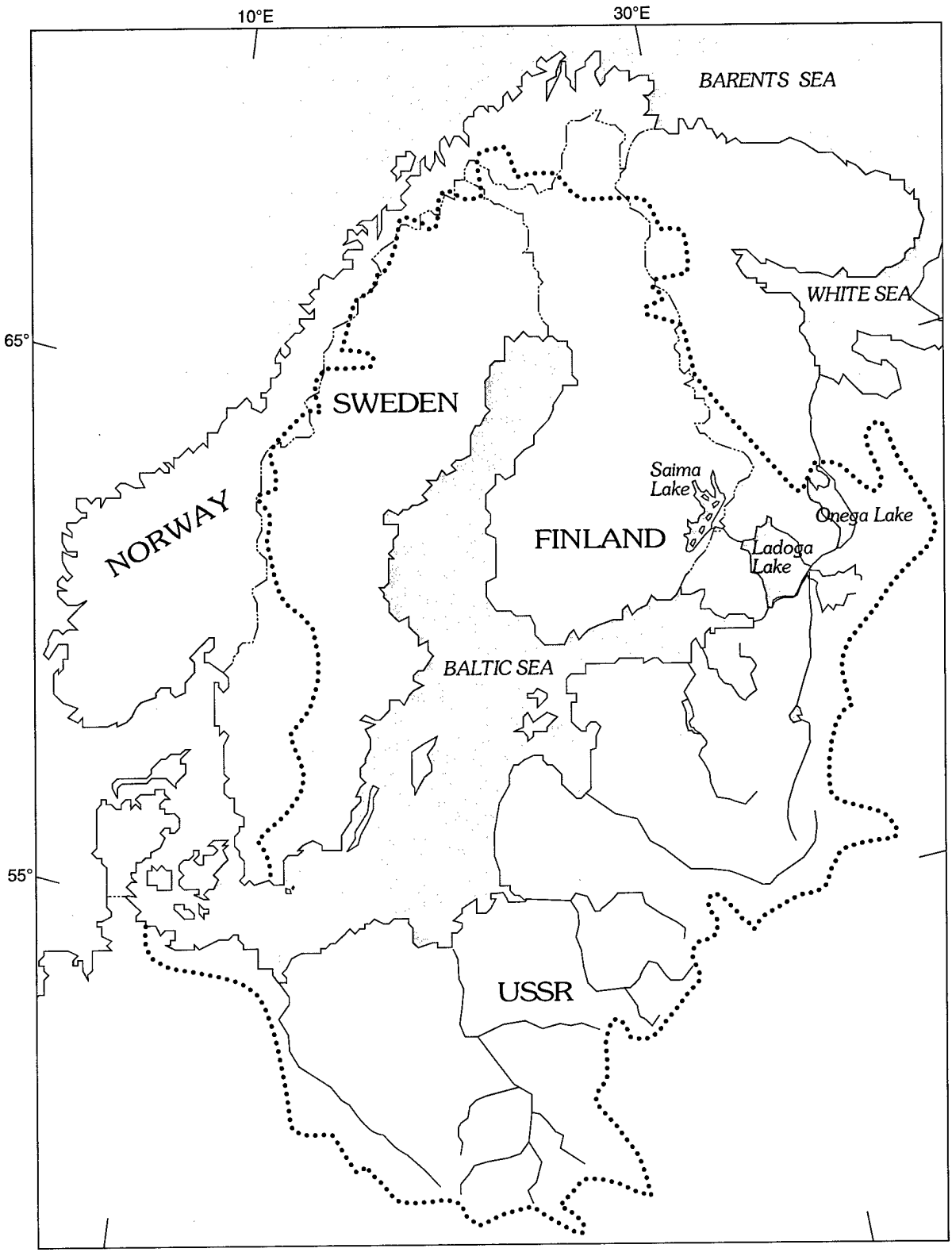

Figure 6. Borders of the Baltic Sea basin (Antonov 1987).

Intrapopulation Variation

Intrapopulation variation in Atlantic salmon has not been studied. We examined genetic features of salmon from two Pechora River tributaries, Pizhma and Upper Pechora. The salmon in this river spawn in about 35 tributaries, some of which are 2,000 km from the mouth. Annually about 100,000 spawners migrate to the Pechora River.

Genetic material was collected over 3 years. Our analysis, based on Hardy-Weinberg equilibrium, did not show any deviations from the theoretically expected distribution of phenotypes. There was no divergence in phenotype distribution in different years either, which indicates genetic homogeneity of salmon in the Pizhma and Upper Pechora.

Comparison of the samples from the Pizma and Upper Pechora showed that the salmon from these tributaries differed from each other at all five loci (Table 1). Of great interest is the "qualitative" divergence of genetic markers of the salmon from the Pizhma and Upper Pechora (Table 2). For all 3 years samples from this locality differed in number of allele at loci Aat-2, Px-2, and Idh-3. The Aat-2 and Px-2 loci were three alleles in Pizhma and two-alleles in the Upper Pechora. In the salmon stocks from the Upper Pechora the Idh-3 locus appeared to be two alleles and in the Pizhma stock monomorphic.

Table 1. Differences between salmon from various parts of the Pechora River on the allele frequencies at polymorphic loci (X^2 test)

[Reliability near * - $p \leq 0.015$; ** - $p \leq 0.001$]

Loci	df	2
Px-2	2	7.50*
S^{Aat-2}	2	8.92*
Sdh-1	1	5.24*
m^{Me-2}	1	19.58**
Idh-3	1	9.70**

The genetic differentiation of Atlantic salmon within the same population (Pechora River) may be very strong. Reproductive isolation of salmon groups from the Pizhma and Upper Pechora is so strong and lasts so long that some populations of this species can exist in all hydrographic systems of the same river. This peculiarity of Atlantic salmon population structure should be taken into consideration when developing protection, reproduction, and exploitation strategies.

Table 2. Differences between salmon from various parts of the Pechora River on the allele number at polymorphic loci

[+ shows the presence of alleles; – shows the absence of alleles]

	Px-2			S^{Aat-2}			Idh-3	
Location	140	120	100	100	76	57	116	110
Pizma	+	+	+	+	+	+	–	+
Upper Pechora	–	+	+	+	+	–	+	+

Changes in Genetic Structure Caused by Fishery Management

Atlantic salmon rearing in hatcheries has increased greatly, and its economic and ecological effects are gradually increasing. According to North Atlantic Salmon Commission data, about 30% of all salmon caught in the world are of hatchery origin, and International Council for the Exploration of the Seas data indicate 60% of salmon caught in the Baltic Sea are reared in hatcheries.

Salmon rearing and restoration programs require the transport of eggs and juveniles. Salmon from the Neva River have been used for this purpose for a long time. However, the transportation of Neva salmon is carried out without any genetic control.

Figure 7 shows a dendrogram of genetic similarity of salmon from the Neva River (U.S.S.R.) and salmon of Neva origin caught in other rivers and from hatcheries of the U.S.S.R. (Narova) and Finland (Laukaam Guttorp, Olkiluoto). In the Guttorp hatchery (the Atland Islands) we examined salmon of Neva origin brought from Laukaa (Guttorp I) and progeny of tagged fish released in the central Baltic and recaptured in the sea (Guttorp II). The samples from the Daugava River (Gulf of Riga) and the Iijoki River (Bothnian Gulf) were taken for comparison as well.

Apparently, there is significant genetic divergence between the Neva salmon from any place and the salmon from the Iijoki River, the coldest part of the Baltic - the Bothnian Gulf. Salmon of Neva origin also differ from those of the Daugava River. We think

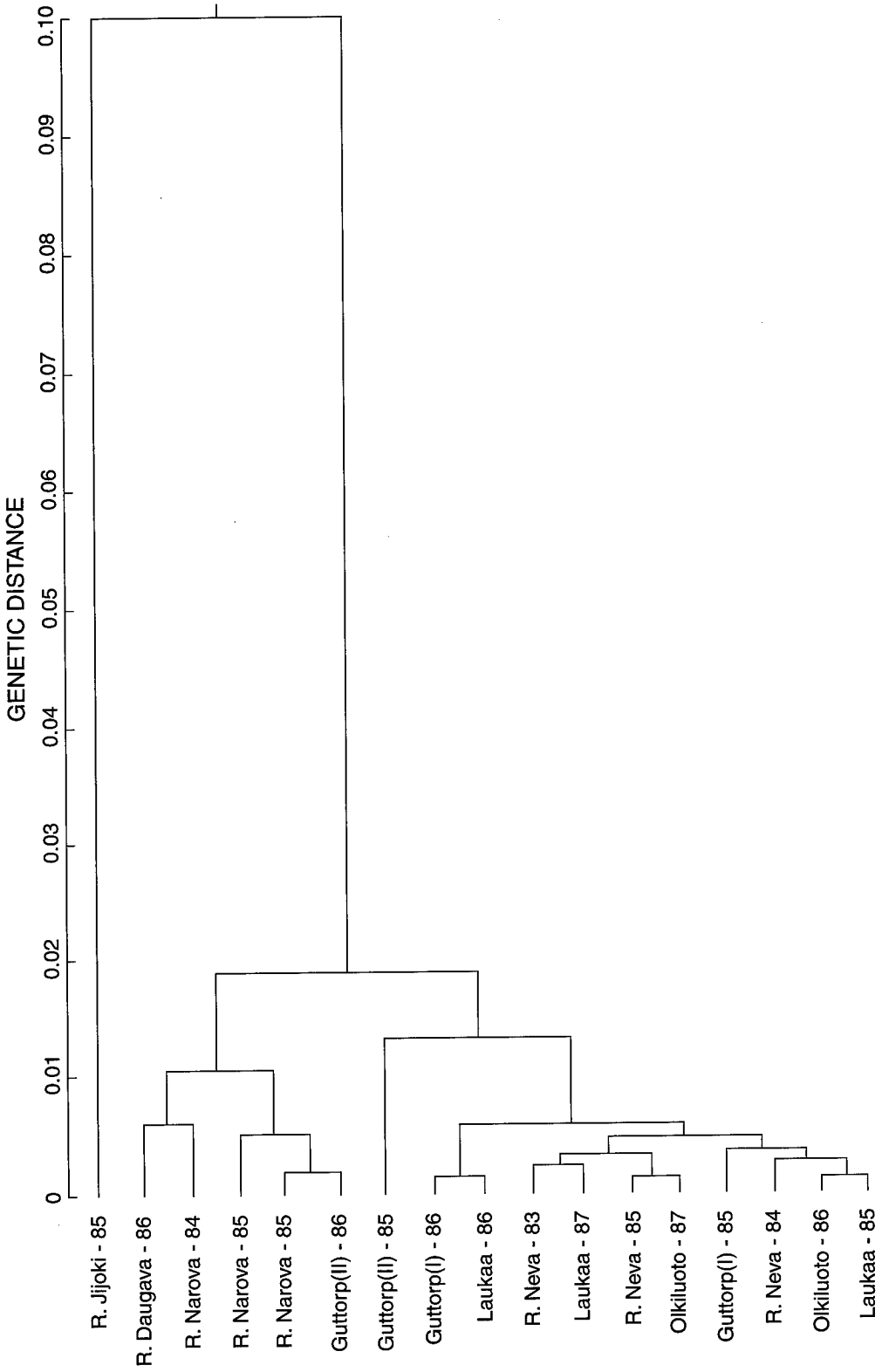

Figure 7. Dendrogram of genetic divergence of Neva origin Atlantic salmon from different locations.

the genetic divergence of salmon from one origin may point to the gene flow resulting from unsystematic use of donor material. The material of genetically different parts of the population is taken and carried to any hatchery, where it is reproduced. Hence, these differences fix in a number of generations. Even different generations of the same localities differed genetically among each other. For example, we note the genetic stability discovered in natural populations.

Unfortunately, genetic data are rarely taken into consideration in fishery management. World practice shows that unsystematic use of donor material often causes genetic erosion of populations, which is supported by our data (Table 3). The main reason for the great decrease in genetic heterogeneity in salmon populations of small reproductive size is the use of a small number of spawners in fishing management.

All of this information, taken as a whole, accounts for the complex interpopulation genetic structure of the Atlantic salmon, at least in rivers with different ecological conditions. This species also has significant intrapopulation genetic divergence. These peculiarities should be considered in fishery management so as not to cause an artificial reduction of population genetic resources. Genetic peculiarities of salmon should specifically be taken into account when gathering donor material, conducting reproductive work, and choosing the regime of exploitation and population protection.

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Table 3. The heterogeneity indices in Atlantic salmon populations

[* - reliability near $p \leq 0.01$]

Populations	Number of populations	H_o	N_a
Natural	9	0.34±0.014	2.09
Hatchery[a]	12	0.29±0.013*	2.04
Natural	9	0.34±0.014	2.09
Hatchery[b]	6	0.28±0.015*	2.06
Large reproductive size	13	0.32±0.013	2.08
Small reproductive size	4	0.26±0.019*	1.96

[a]Including hatchery populations with spawners from natural populations.

[b]Including only "pure" hatchery populations.

Striped Bass Culture and Its Future

by

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Abstract. Striped bass (*Morone saxatilis*) is an important aquacultural species in the United States because of its euryhaline tolerance and value as a recreational and commercial fishery. Primarily considered a marine or estuarine piscivore, striped bass have been stocked successfully in many freshwater reservoirs, with several populations adapting and reproducing naturally in these systems. Because coastal populations of striped bass have been depleted recently, primarily by overfishing and pollution of spawning and nursery habitats, the development of techniques for large-scale aquaculture has become increasingly vital to support reservoir stocking, restore coastal populations, and develop a commercial market.

Striped bass are cultured with intensive and extensive techniques. Most propagation is accomplished using wild-caught broodfish. Ovulation is induced by chorionic gonadotropin injection, and gametes are manually stripped from the fish and fertilized. Egg incubation methods vary between freshwater and brackish water spawning facilities. Larvae are normally ready to begin feeding about 5 days after hatching. Intensive culture facilities use tank systems, feed *Artemia* nauplii for the first few weeks after mouthpart development, and gradually wean the fish onto a prepared diet. Extensive production involves stocking fry into fertilized ponds and harvesting 35–40-mm (total length) fish after 45–60 days. These juveniles, called "Phase I" striped bass, are then stocked into production ponds and fed prepared feed until they reach the desired size.

At present, few commercial aquaculturists in the United States raise striped bass to marketable size, although some produce hybrids (*M. saxatilis* x *M. chrysops*). Most striped bass production is done by state and federal agencies or private organizations involved with reservoir stocking or coastal population restoration efforts. These programs usually rear fish to only 1–6 months of age before release, so little information is available on the costs involved in rearing market-size fish.

Research into most aspects of striped bass aquaculture is needed. There are no commercial diets formulated specifically for striped bass, and the dietary requirements for all phases (fry through broodstock) are unknown. Domesticated strains of broodstock and controlled spawning techniques are needed to increase availability of fry, as well as improved larval rearing techniques to maximize viability and survival. Refined techniques for semi-intensive pond production are being investigated, along with the development of high density tank culture. Restrictions on future harvests have increased interest in the commercial rearing of striped bass to marketable size. Application of advanced technology to increase production is essential to the future success of commercial aquaculture operations. Overall, the potential for aquaculture of striped bass is substantial, and researchers are striving to refine production techniques to support this effort.

Striped bass (*Morone saxatilis*) are one of the most prized game fish in the United States and once supported a large commercial fishery. Native populations were found along the Atlantic coast from Maine to Florida and in the Gulf of Mexico from northern Florida to eastern Texas (Raney et al. 1952). In addition, Pacific coast populations were established by stocking in the late 1800's. The striped bass is basically a marine or estuarine piscivore; however, its euryhaline tolerance has enabled stocking into selected large lakes and reservoirs to establish recreational fisheries. Some populations in these lakes have adapted to freshwater and are reproducing naturally.

Coastal populations of striped bass supported large recreational and commercial fisheries. Annual catches rose to 6,683 metric tons (t) in 1973 but then began to decline. The Atlantic fishery was closed in 1985, and research intensified into determining the causes of the decline (Richards and Deuel 1987). The decline in coastal populations seems to be due primarily to overfishing and loss of nursery habitat. Nursery areas are primarily coastal wetlands, which are rapidly being altered due to pollution, urban development, and reduced freshwater inflow (Hall et al. 1985; Buckler et al. 1987; Mehrle et al. 1987).

Culture of striped bass is conducted for three main purposes: development and maintenance of inland freshwater fisheries, coastal population restoration, and commercial aquaculture. Culture techniques for all three purposes are similar, although production philosophies often diverge. In genetics, for example, commercial aquaculturists want to develop "domesticated" broodstock strains that perform better under hatchery conditions. Culturists producing fish for restoration purposes, however, want to preserve "wild" characteristics and protect gene pool variability. Breeding schemes for these two goals are very different. Additionally, stocking programs routinely produce fish between 25 and 300 mm TL (1 month to 1 year production period), whereas commercial aquaculture wants larger market-size fish (up to 18 months of production).

Hatchery-produced fish are routinely stocked into many inland freshwater lakes to support recreational fishing. Currently, 36 states support inland striped bass fisheries, with 456 reservoirs stocked with striped bass or hybrids (Stevens 1984). Although many of these initial stockings were produced from coastal fish reared in hatcheries, several large reservoir and river systems have now developed reproducing populations. Evidence of this was first documented by Scruggs (1957) in the Santee-Cooper reservoir system, South Carolina. Most states manage these fisheries with a combination of natural recruitment, regulated fishing, and periodic stocking of hatchery-reared fish (Bailey 1975).

Hatchery fish are also stocked into coastal waters to supplement natural populations and increase recruitment. Most of the Atlantic stock of striped bass originate in the Hudson River or Chesapeake Bay systems, with a small contribution from North Carolina (Fabrizio 1987). Hudson River populations have been protected since 1976, by closure of the fishery because of contamination of adult fish with polychlorinated biphenols (PCB). Chesapeake Bay fish were severely affected by commercial fishing and environmental degradation, resulting in the closure of the Atlantic fishery in 1985 (Richards and Deuel 1987). Gulf of Mexico and Pacific populations were subjected to reduced freshwater inflows because of river diversions for industry and agriculture, which drastically changed spawning and nursery habitat. Federal, state, and private mitigation hatcheries supply juvenile fish for release into coastal waters to supplement natural recruitment and restore populations. Most restoration programs include the stocking of phase 1 (25–60 mm TL) or phase 2 (45–250 mm TL) fish, although the State of California releases yearlings. In total, federal and state hatcheries produce about 40 million juveniles per year for release into reservoirs and coastal waters in the United States (Geiger and Parker 1985).

Recently, commercial aquaculture of striped bass and several of its hybrids has become economically and technologically feasible. Improvements in culture techniques developed for supporting stocking programs have direct application to the commercial aquaculture industry. Additionally, closure of commercial fisheries has created a high market demand and corresponding high price (Liao 1986). Hybrid striped bass are preferred for commercial aquaculture because of their more rapid growth, greater tolerance of hatchery conditions, and acceptance of prepared diets (Bayless 1972; Smith et al. 1986). Hybrids were once thought to be sterile; however, recent research has documented their spawning in tank systems and in the wild (Forshage et al. 1986; Smith and Jenkins 1986; Fries and Harvey 1989). The most common hybrids are crosses between striped bass and white bass (*M. chrysops*), although crosses with yellow bass

(*M. mississippiensis*) and white perch (*M. americana*) are also made. Hybrids generally have a deeper body shape and irregular horizontal stripes compared with striped bass (Bayless 1972; Kerby et al. 1982).

Intensive and extensive culture methods are used to produce fish for all three goals. Intensive methods are usually tank or raceway high density systems, with high feeding rates of pelleted diets, high stocking densities, and closely monitored water quality. Extensive production is accomplished in fertilized ponds. Fish are stocked at moderate stocking densities and fed commercial diets or forage. For the purposes of this paper, striped bass culture will be divided into the following stages: reproduction, larval rearing or phase 1 (fry to 35-mm TL fish), phase 2 production, and growout to market size. Owing to the relatively recent development of commercial aquaculture, little information is available on production of fish to market size (0.5 kg or large).

Reproduction

Most striped bass reproduction is still accomplished by the collection of mature fish during the spawning season. Spawning season occurs March through June, depending on latitude and water temperature (usually 16–19°C). Early research indicated that males mature at 2 years, while females normally do not mature until at least 3 years (Setzler et al. 1980). However, more current information indicates that males do not mature until age 3, and females do not mature until age 7 or older (Dew 1988). Fecundity estimates range from 136,400 to 246,400 eggs/kg of body weight (Morgan and Gerlach 1950; Jackson and Tiller 1952; Lewis and Bonner 1966). Broodfish are collected by seines, nets, or electroshocking and are transported to the spawning facility. Ovarian tissue is removed by catheterization, and the stage of maturation is determined by microscopic examination (Bonn et al. 1976). Maturation must be sufficiently advanced for human chorionic gonadotropin (HCG) to be effective in inducing ovulation (Stevens 1966). Ovulation is induced by injection of chorionic gonadotropin (220–300 IU/kg body weight), and the fish are then strip-spawned or tank spawned (Stevens 1966; Bayless 1972; Bishop 1975). Ovulation may take 1–7 days depending on the stage of maturation, associated capture and handling stress, and water temperature. Males are sometimes injected with HCG at 110–165 IU/kg of body weight to increase milt volume (Harrell 1984).

Fertilized eggs are about 1 mm in diameter, clear with a green-gold oil globule. Differences in oil content between freshwater and estuarine populations affect egg buoyancy. Freshwater eggs can be hatched in jars (such as McDonald jars), whereas estuarine eggs float and need a pelagic incubation environment (Bonn et al. 1976). Eggs hatch within 2–3 days after spawning at 16–18°C, and newly hatched larvae are about 4 mm TL. Development of the digestive tract and mouthparts takes about 5 days, and then the larvae are ready to begin feeding. Larvae are especially sensitive to handling between 2 and 4 days posthatch, so they are usually shipped at 5 days or older (Bayless 1972).

Several limitations of this spawning method are obvious. Reproduction is limited to the natural spawning season, March through June, and, depending on location, is usually only about 60 days long. Unusual weather conditions and scarcity of broodfish will affect production. A lot of manpower is expended in capturing broodfish, and no genetic breeding programs can be established. Also, the chorionic gonadotropin-induced ovulation method is only effective on females in the later stages of maturation, which further reduces the availability of broodstock. Broodfish scarcity is considered a major impediment to the large-scale development of striped bass and hybrid commercial aquaculture (Joint Subcommittee on Aquaculture 1983). In addition, reliance on wild-caught broodstock does not allow the development of domesticated strains or specific controlled breeding schedules for selected traits.

Ongoing research programs are attempting to overcome some of these obstacles. Researchers at North Caroline State University are studying the changes in blood hormone concentrations during the annual cycle to define when vitellogenesis and maturation occur. This work is also attempting to characterize, isolate, and synthesize striped bass gonadotropin (C. Sullivan, North Carolina State University, personal commun.). The effectiveness of alternate spawning hormones such as luteinizing hormone-releasing hormone (LHRH) analogues and salmon gonadotropin (SnGnRH), and dopamine blocking agents such as primozide and domperidone, is being compared with HCG for inducing maturation and spawning in females at various stages of maturation. Initial trials indicate that LHRHa and SnGnRH are effective in

inducing maturation and spawning (author's research, in progress). Several laboratories are maintaining adult striped bass in tank systems and attempting to induce spawning under controlled conditions. The Crane Aquaculture Facility, supported by Baltimore Gas and Electric Power Company and the University of Maryland, has maintained selected year classes of fish in large tank systems. These fish have been reared continuously in an intensive culture system and represent one of the first attempts to close the life cycle of striped bass (C. Woods, Crane Aquaculture Facility, personal commun.). The U.S. Fish and Wildlife Service Fish Culture Research Laboratory is maintaining adult striped bass in recirculating environmentally controlled tank systems and is attempting to induce out-of-season maturation and spawning by manipulating temperature and photoperiod (Smith and Jenkins 1986; Henderson-Arzapalo and Colura 1987). Several federal and state hatcheries are maintaining groups of adult striped bass with known genetic characteristics in ponds for use in producing particular strains; this is an important effort in the restoration of the Gulf of Mexico population (Wirgin et al. 1989). These avenues of research may help improve and control reproduction, as well as develop strains of striped bass with known genetic histories.

Larval Rearing and Phase I Production

Larval rearing is still the major obstacle in striped bass production. As stated previously, striped bass larvae take about 5 days at 18°C to develop mouthparts and a digestive tract. Initially, larvae will only accept live food (Bonn et al. 1976). Newly hatched *Artemia* may be fed to larvae between 5 and 21 days old in intensive culture, although *Artemia* are known to be deficient in several essential fatty acids (Fujita et al. 1980; Leger et al. 1986). This problem is circumvented in large production facilities by stocking 5-day-old larvae directly into prepared ponds, where the larvae feed on zooplankton.

The main problems during larval rearing are providing adequate nutrition, maintaining water quality, and failure of the swim bladder to properly inflate. As with most small predacious fish larvae, these problems are exacerbated in intensive culture. Pond culture circumvents these problems somewhat by allowing the fish to grow under more "natural" conditions. The development of striped bass intensive culture techniques and the associated problems are discussed by Carlberg et al. (1984). The lack of an acceptable larval diet means culturists are forced to culture food organisms as well as maintain the fish. *Artemia* or prepared larval diets can be deficient in essential nutrients and can cause fouling of the tank water and fungus problems. Optimal maintenance conditions for larvae are water temperatures of 16–20°C, >3.0 mg/L dissolved oxygen, and 3–10 ppt salinity (Bonn et al. 1976). As the fish grow, optimal temperature for growth shifts to 24–26°C (Cox and Coutant 1981). Culture in brackish water significantly increases larval tolerance of high temperature and ammonia (Morgan et al. 1981; Colura and Henderson-Arzapalo 1988). The major problem in rearing of striped bass larvae, however, is the failure of the swim bladder to inflate in many fish (Doroshev et al. 1981; Lewis et al. 1981). Striped bass larvae normally inflate swim bladders between 5 and 10 days posthatch (Doroshev et al. 1981). Fish require access to the water surface to inflate initially, and this ability is affected by several factors (Chapman et al. 1988). Incubation temperature, high total dissolved gas pressure, and the presence of surface films (such as oil) resulting from decaying food or dead larvae are the most commonly cited causes for failure to inflate (Cornacchia and Colt 1984; Hadley et al. 1987). Fish without inflated swim bladders will survive in intensive culture (presumably not in the wild) but growth is poor and resistance to stress and disease is low.

Some improvements in larval rearing environments, such as improved water flow patterns and removal of surface oils that block the air-water interface, improve inflation rates (Friedmann and Bates 1988). There is wide variation in the design of larval rearing systems, and most intensive culture facilities are still attempting to optimize environmental conditions and stocking density. Recent research indicates that triiodothyronine injection into the female just prior to spawning increases larval growth rate, survival, and swim bladder inflation (Brown et al. 1988). Some larval nutrition programs focus on improvement of live food culture and the supplementation of live food with essential nutrients. Initial trials feeding *Artemia* supplemented with an essential fatty acid emulsion indicated that larval survival was improved (C. Lemm, U.S. Fish and Wildlife Service, personal commun.). However, the ultimate solution to larval nutrition is the development of complete larval diets that are readily palatable, improve survival, eliminate

the need for culturing live food organisms, and do not foul tank water. Some areas being examined include the use of chemoattractants to enhance palatability (S. Hughes, U.S. Fish and Wildlife Service, personal commun.), new feed manufacturing processes such as marumerizing (a Japanese process that makes very small firm extruded pellets), and microsencapsulation (binding finely ground nutrients ina polymer coating) to make microparticulate feed of acceptable sizes and composition (R. Burrow, U.S. Fish and Wildlife Service, personal commun.). Additional research is still needed on the basic nutritional requirements of larval striped bass. The alternate and more commonly used larval culture method is phase 1 pond production, where fry are stocked into prepared ponds. A typical culture pond is usually 0.2 to 0.8 ha and is stocked at 165–220,000 fry/ha. Ponds are managed to maximize suitable forage zooplankton by a combination of timed filling and draining, additions of organic and inorganic fertilizers, and inoculation of desired organisms (Braschler 1975; Geiger 1983a, b). Preferred natural forage of striped bass consists primarily of small cladocereans, copepod nauplii, and adults (Sandoz and Johnston 1965; Humphries and Cummings 1972). When larvae reach about 20 mm TL, they also begin to utilize benthic organisms (Harper et al. 1968). Supplemental feed such as salmon starter diets is often offered towards the end of larval pond production as zooplankton populations are depleted. Harvest normally occurs when the fish reach 25–50 mm TL, which takes between 30 and 60 days. This size of fish is called a phase 1 fingerling. After harvest, fingerlings are usually graded and restocked in the ponds or tank systems for continued growth. This second period is called phase 2 production. A detailed description of typical phase 1 pond production procedures is presented by Turner (1984).

Pond survival and production is erratic and unpredictable. Populations of forage zooplankton often are depleted before the fish are ready for harvest or may not be suitable forage in terms of species composition, size, or density. Production is highly dependent on weather conditions, and a careful balance must be maintained among water quality, stocking density, and zooplankton density. Pond fertilization methods and zooplankton management vary widely because of the variability in water characteristics at different production facilities.

Pond culture methods are being developed to increase production of forage organisms and phase 1 survival and growth. Fertilization rates and composition, manipulation of water chemistry, and supplemental aeration are being investigated as means to improve production. Improvements to the pond's physical structure such as drying the pond bottom between uses (oxidizes excess nutrients), and better harvest structures, such as concrete kettles that concentrate the fish during draining, help improve survival. Culturing fry in slightly brackish water (3–10 ppt) has also demonstrated significantly better production. Some facilities set aside one intensively managed pond for zooplankton and then use this zooplankton as inoculant in newly filled ponds to rapidly develop forage populations (Geiger and Parker 1985). The development of specific striped bass diets may reduce the reliance on natural forage and improve tank culture and pond culture. Evaluations of nutritional requirements, dietary protein, lipid, and carbohydrate sources are needed. A summary of some of the current research information on nutrition of striped bass is shown in Table 1.

Phase 2 Production

Phase 1 fingerlings are usually graded after harvest to reduce cannibalism and then stocked back into production ponds at 5–20,000 fish/ha. Fish are fed prepared diets (usually trout or salmon feed) and reared for several months (usually until November-December) until they reach 100–250 mm TL and are 6–8 months old.

Some aquaculture facilities combine phase 1 pond production and phase 2 intensive tank culture. Larval culture is conducted in fertilized production ponds. Phase 1 ponds are harvested, and fingerlings are graded, prophylactically treated for parasites and handling stress, and stocked into intensive culture tank systems. Raceways or large circular tanks with high water exchange rates and supplemental aeration are used. Fish are fed commercial salmon or trout feed and graded periodically to prevent cannibalism (Carlberg et al. 1984).

Table 1.--Comparison of reported nutrition and diet research conducted with striped bass juveniles. (This information was provided by C. Lemm, Fish Culture Research Laboratory, U.S. Fish and Wildlife Service.)

Information	Fish size (gram)	Temperature (degrees Celsius)	Diet levels (percent) Protein	Lipid	Feeding level (percent)	SGR[a] (percent per day)	Carcass composition (percent) Protein	Lipid	Study period	Source
Milliken (1982a,b)	2–8	24	55	16	Satiation	4.6	47.7	35.7	6 weeks	Test diets
Milliken (1983)	2–10	20	47	12	Satiation	3.6	52.2	41.0	10 weeks	Test diets
			57	17	3.8	53.0	40.5			
Berger/Halver (1987)	9–11	21–22	52	17	2.5 Body wt.	NA	51.7	38.4	6 weeks	Test diets
	11–16		45	17	2.5 Body wt.	NA	48.4	38.9		
Klar/Parker (1989)	25–56	20	44	13	2 Body wt./sat.	1.9	(1.7, 0.9)[b]		8 weeks	Trout grower[c]
			58	16		1.7	(2.9, 1.3)[b]			Salmon diet[c]
			39	8		1.5	(2.1, 1.0)[b]			Trout grower
Klar/Parker (1989)	34–289	Variable (Ponds)	39	8	Considered	0.8–1.2	NA	NA	11 months	Trout grower
			40	4	Excess	0.1–1.4	NA	NA		Mod. catfish
Fish Culture Lab (1989)[d]	2–90	24	54	17	Satiation	3.4	45.8	41.6	16 weeks	ASD2-30
			38	8		2.9	55.2	29.1		Trout grower
Fish Culture Lab (1990)[d]	1–7	20	52-57	12-15	5 Body wt.	3.6	NA	NA	6 weeks	Test diets

[a]Specific growth rate: percent gain in weight/day; ($\log_e$ end weight - $\log_e$ beginning weight)/days x 100.

[b]First value is grams of abdominal fat; second value is percent muscle fat.

[c]Trout grower and salmon diet are open-formula diets of the U.S. Fish and Wildlife Service, GR6-30 and ASD2-30, respectively.

[d]Data under analysis (C. Lemm, U.S. Fish and Wildlife Service, personal communication).

Growout to Market Production

Most stocking programs only produce phase 1 or phase 2 fish for release, so little information is available on the continued growth of phase 2 fish to market size, about 0.5–1 kg. Market production may be done by intensive tank culture, in pond systems, or by cage or net-pen culture in open reservoirs or estuaries.

Most of the information available on production of marketable fish was developed by pilot commercial aquaculture evaluations, and most studies used hybrid striped bass. Smith (1987) reported production of 8,323 kg/ha with hybrids averaging 755 g at 21 months old. Early market production by Powell (1973) and Valenti et al. (1976) used brackish water cage culture, which resulted in promising growth rates; however, cold winter temperatures caused high mortality. Later research by Williams et al. (1981) also demonstrated high growth rates and survival with hybrids in estuarine net-pens over 1 year; however, no feeding or growth occurred at temperatures <15°C. Kerby et al. (1982) reported results of rearing hybrids to commercial size in ponds, pools, and cages. Pond production ranged from 2,312 to 4,886 kg/ha after 13 months. This preliminary information indicates that production of market-size fish is technically feasible, with further refinement as to stocking densities, diets, and maintenance of the fish through cold weather. The use of heated power plant effluent or other sources of warm water probably would greatly improve growth, shorten the production period, and increase profitability.

Nutrition and Diet

In the wild, striped bass are carnivorous, preying on small fish, small invertebrates, and insects (Gardinier and Hoff 1982; Wilde and Paulson 1989). Diets used for striped bass aquaculture were usually manufactured for salmon, trout, and occasionally, catfish. Through trial and error, most culturists have found that striped bass prefer high protein diets (also high in fish meal and fish oil) such as trout or salmon diets. Millikin (1982a,b) found striped bass less than 8 g reared at 24°C required a diet containing 55% crude protein for maximum growth and feed efficiency. The diet was composed of nearly 50% fish meal and 50% isolated soy proteinate. At 20°C, a diet with 47% protein and 12% lipid provided maximum growth for less than 10 g striped bass. The diet containing 57% protein and 17% lipid provided the same growth as the 47% protein and 12% lipid diet. These results demonstrated a protein sparing action of increasing dietary lipid as well as demonstrating the accepted premise that protein and energy requirements are related to water temperature (Millikin 1983). Berger and Halver (1987) found a protein requirement of 52–55% for 9–11 g striped bass at 21–22°C. In protein and energy studies, these authors found growth was maximal and equal when a 45% protein diet contained either 17% lipid or 33% dextrin as the energy source.

In evaluating commercially available diets in pond culture, Klar and Parker (1989) found the highest specific growth rate (percent gain in weight/day) was obtained in 25–56-g striped bass fingerlings when a trout grower diet (44% protein, 13% lipid) was fed, followed by an Atlantic salmon diet (58% protein, 16% lipid) and a lower protein commercial trout grower (39% protein, 8% lipid). The food conversions were 2.57, 2.90, and 3.10 respectively. Feeding the Atlantic salmon diet to fish of this size resulted in increased body fat deposition and, as a result, was inefficient in terms of nutrient use and uneconomical in terms of feed cost. Klar and Parker (1989) also compared a commercial trout grower diet (39% protein, 8% lipid) and a modified catfish diet (40% protein, 3.4% lipid) for growout of yearling striped bass in ponds for 11 months. The modified catfish diet seemed to provide sufficient nutrition for maintenance when water temperatures were low (down to 10°C) and energy requirements were probably low. When the water temperature increased in spring the trout grower diet provided better nutrition. Survival of fish was 43% (trout grower) and 28% (modified catfish).

Nutrition research conducted by the U.S. Fish and Wildlife Service Fish Cultures Research Laboratory has indicated abnormal liver tissue structure in striped bass maintained on trout formulation diets (Lemm et al. 1989). The study included the feeding of the Atlantic salmon and trout grower diets from the end of phase 1 (1–2 g) through phase 2 (75–100 g). As in the study by Klar and Parker, the striped bass fed the Atlantic salmon diet for the full 16 weeks contained an excess of body fat. The feeding of the commercial trout grower for the same period provided good growth of fish; however, within 2 weeks of feeding this diet, the livers of the fish had significant

degenerative changes. The cause of the liver pathology is under investigation. Those fed the Atlantic salmon diet had glycogen-filled livers, characteristic of intensively reared salmonids, but no liver pathology. The problem probably relates to the amount and type of lipid present in the diet, and future research will examine the effects of different oil sources on growth, survival, blood chemistry, and tissue structure and composition (C. Lemm. U.S. Fish and Wildlife Service, personal commun.). Review of the early growth periods, in conjunction with review of liver sections for the same period, indicate that the Atlantic salmon diet or its equivalent (high protein and high energy) is useful for the first 4–6 weeks following removal from phase 1 rearing ponds. This corresponds to a 10–13-g fish and equates to the period of feeding No. 1 through No. 4 size feed granules. A less nutrient-dense diet for growout is then more reasonable in terms of feed cost, efficiency, and health of the fish.

Table 1 summarizes some of the current research on striped bass nutrition. As striped bass aquaculture becomes more widespread, diets formulated specifically for striped bass will be needed. Research is still needed to define amino acid, fatty acid, and vitamin requirements for each life history stage, from fry through broodfish, as well as protein:energy ratios and digestibility of various feed ingredients.

Diseases

Only a few diseases have been problematic in striped bass culture, although the occurrence and identification of the pathogens is expected to increase as aquaculture becomes more common. Mitchell (1984) and McAllister et al. (1987) provided the most complete listings of disease problems in striped bass. The parasitic ciliates *Trichodina* sp., *Ambiphrya* sp., *Apiosoma* sp., and *Epitheliocystis* occur frequently at high densities, but whether these organisms cause mortalities directly is doubtful. The yellow grub, *Clinostomum* sp., also occurs; however, except for being visually unappealing to fishermen, it causes few problems. Only *Flexibacter columnaris* has been identified as a serious bacterial disease problem. *Aeromonas*, *Pseudomonas*, and *Vibrio* sp. have also been isolated, but these are usually associated with general stress reactions. Striped bass do carry the infectious pancreatic necrosis virus (IPN) but are not affected by it (Wechsler et al. 1987). They can shed the virus, however, and transmit it to susceptible species (McAllister and McAllister 1988). There have also been reported instances of mortalities associated with *Mycobacterium marinum* (Hedrick et al. 1987)., *Edwardsiella tarda* (Herman and Bullock 1986), and *Pasteurella piscicida* (Hawke et al. 1987). The main health problem with striped bass is an extreme physiological reaction to stress; prophylactic treatments before and after handling and transport are essential for preventing mortality. The use of soft nets to reduce abrasion and scale loss, mild tranquilizers, and maintaining 3–10 ppt salt (NaCl) in the culture water reduces handling stress significantly (Mazik et al. 1991; Tomasso et al. 1980).

The development of commercial aquaculture has increased the need for testing and registration of new therapeutics and chemicals. As with most aquaculture species raised in the United States, the choice of legal, registered drugs and chemical treatments is limited. The testing required to evaluate and register a treatment chemical with the Food and Drug Administration (FDA) is expensive, and drug manufacturers only test chemicals in which they feel there is a substantial profit. A current list of FDA-approved therapeutics was presented by Schnick (1988). Additional research is needed to provide the needed information for drug registration. Currently, only tricaine methanesulfonate (MS-222) is approved for use as an anesthetic on striped bass; it often causes detrimental side effects such as reduced pH in poorly buffered water and violent reaction during recovery. The use of benzocaine (Allen 1988) and etomidate (Plumb et al. 1983) as alternatives is currently being evaluated (Allen 1988). Testing of formalin and terramycin for use on market-size striped bass is ongoing, and clearance is expected soon (W. Rogers, Auburn University, personal commun.). As commercial aquaculture develops into a profitable industry, other therapeutics will be available.

Summary

Although striped bass aquaculture has been practiced for almost 25 years, the advent of commercial production has provided the greatest impetus for improved culture technology. The main goal of most striped bass production is still to provide fish for reser-

voir stocking and coastal population restoration programs. The restoration program on the Atlantic coast seems to be succeeding: reproductive indices of Chesapeake Bay fish have increased primarily due to protection from fishing pressure. The stability of the population may change, however, once the fishery is opened. Atlantic striped bass fisheries will never support harvests similar to those taken during the 1970's, and commercial aquaculture of marketable fish is an attractive and profitable alternative. Development of this industry is dependent on the further refinement of reproduction, larval rearing, nutrition, and disease treatment techniques. The potential market for striped bass is large, and various stocking programs can be expected to continue as long as fishing pressure remains high. As a method to satisfy the consumer market, as well as supporting recreational fishing, the future of striped bass aquaculture seems bright.

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Influence of Contaminants on Survival of Striped Bass in Chesapeake Bay Tributaries

by

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Abstract. Striped bass (*Morone saxatilis*) have long supported an important recreational and commercial fishery resource along the east coast of North America; however, populations declined severely after 1970. Excessive fishing pressure and the presence of contaminants in prime spawning areas seem to be major contributors to this decline. Although no individual contaminant has been detected at acutely toxic concentrations, laboratory studies indicate that combinations of contaminants in spawning areas could significantly decrease the survival of larvae. In addition, larval striped bass are extremely sensitive to inorganic elements in the presence of reduced pH.

The Nanticoke and Choptank Rivers, two Chesapeake Bay tributaries, represent historically productive spawning areas for striped bass. To evaluate the survival of larval striped bass throughout the spawning season, we conducted a total of 20 toxicity tests—four each at three locations in the Nanticoke River and two locations in the Choptank River in spring 1989. Striped bass larvae (48 h old) were placed in environmental chambers, and survival was estimated daily for 4 days. Dissolved oxygen, pH, salinity, conductivity, and temperature were measured hourly throughout the spawning period with submersible water quality monitors. Water samples for contaminant analysis were collected daily during each study and periodically between studies.

Survival was low in all tests, and no larvae survived in 14 of the 20 tests. No salinity was detected at any location during any test; larval mortality was highest during periods of low pH (6.0–6.4). Concentrations of aluminum and copper were elevated during periods of highest larval mortality in both rivers. In addition, cadmium concentrations in the Choptank River were as high as 23 µg/L. Other contaminants, including lead, nickel, chromium, arsenic, and selenium, were present in trace amounts in both rivers. These observations indicate that the presence of these contaminants combined with conditions of low pH and low salinity greatly reduced larval survival. Regardless of the intensity of fishing pressure, persistence of these adverse water quality and contaminant conditions in spawning areas may inhibit the recovery of striped bass populations.

Striped bass (*Morone saxatilis*) have historically been an important recreational and commercial fishery resource along the East Coast of North America. During the 1960's, the commercial harvest of this species along the Atlantic Coast reached record highs, and biologists warned that the stocks supporting this harvest could not withstand the intensive fishing pressure (Koo 1970). By the end of the 1970's, commercial harvest had declined rapidly and continually (Goodyear 1985); similar decreases were also evident in indices of juvenile production (Boreman and Austin 1985). In response to this decline, the Atlantic States Marine Fisheries Commission (1981) instituted a coastwide management plan to regulate harvest of striped bass as a part of its Interstate Fishery Management Program. In addition, the United States Congress passed the Chaffee Amendment to the Anadromous Fish Conservation Act in 1979 (Pub. L. No. 96-118, 16 U.S.C. 757g), establishing an Emergency Striped Bass Study to assess the status of stocks, identify causes for their declines, and evaluate the economic effects of reduced harvest (Chaffee 1980).

As a result of funding from the Chaffee Amendment, the U.S. Fish and Wildlife Service, in cooperation with the National Marine Fisheries Service, initiated a comprehensive research program in 1980 to evaluate the status of striped bass stocks and determine potential causes for their decline. Nine causes were originally suggested as contributing to the decreased production of striped bass: intense fishing pressure, contaminants, food availability, predation, competition, disease, unfavorable climatic events, habitat destruction, and water quality deterioration from poor agricultural and sewage treatment practices. Although no single factor may be responsible for the decline, combinations of these stresses may reduce the ability of the striped bass to persist.

Evaluation of the role of contaminants in the decline of striped bass populations became a major objective of the National Fisheries Contaminant Research Center (NFCRC; formerly the Columbia National Fisheries Research Laboratory or CNFRL). During the first phase of the NFCRC program, a survey was conducted to determine concentrations of organic and inorganic chemicals present in tissues of adult and juvenile striped bass and in eggs collected along the Atlantic Coast and from several major hatcheries (Columbia National Fisheries Research Laboratory 1983). Polychlorinated biphenyls (PCBs), including Aroclors 1248, 1254, and 1260, were the most prevalent organic contaminants detected in fish from the Hudson River, New York; the Nanticoke and Potomac Rivers, Chesapeake Bay, and the Edenton Fish Hatchery, North Carolina. Other chemicals, such as chlordane, DDT, DDD, and DDE, were present but at levels considered biologically insignificant. The major inorganic elements detected in striped bass tissues were lead, cadmium, zinc, mercury, copper, arsenic, and selenium. Although Mehrle et al. (1982) showed a relation between the concentrations of lead, cadmium, and PCBs in juvenile striped bass tissue and the structural integrity of vertebrae, no single chemical was identified during this first phase of research that could have been solely responsible for the decline in striped bass populations.

The second phase of the research effort involved laboratory testing to determine the toxicity of single chemicals and mixtures of these chemicals to striped bass. Acute tests defined the individual toxicities of arsenic, selenium, cadmium, chromium, copper, zinc, and nickel to young striped bass (Palawski et al. 1985). In addition, longer-term partial life-cycle tests were conducted in flow-through proportional diluters to evaluate the toxicity of chemical mixtures at concentrations similar to those measured in Chesapeake Bay tributaries (Mehrle et al. 1987). Results of these initial tests indicated that age of larvae, contaminant concentrations, and salinity of the environment strongly influenced the effects of environmental contamination of the survival of early life-stage striped bass. Additional laboratory exposures indicated that the toxicity of aluminum and a mixture of inorganic contaminants depended on age of fish and pH (Buckler et al. 1987). This inorganic mixture was most toxic to larval striped bass exposed in soft fresh water, and results indicated that although no contaminant was present at acutely toxic levels, the interaction of low pH (from acid deposition) with inorganic contaminants in the environment could contribute to the decline in abundance of East Coast striped bass.

In 1984, NFCRC in cooperation with scientists from Johns Hopkins University began conducting in-situ toxicity tests to assess the survival of larvae in several Chesapeake Bay tributaries. These field studies demonstrated complete mortality of larval striped bass in the soft, poorly buffered water of the Nanticoke River, one of the four primary spawning grounds for striped bass in the Maryland portion of Chesapeake Bay (Columbia National Fisheries

Research Laboratory 1984; Hall et al. 1985). Chemical characterization of river water revealed low pH, low hardness, low salinity, elevated dissolved aluminum, and low levels of lead, cadmium, zinc, arsenic, selenium, and copper.

In contrast, mortality was only 30% in field studies conducted in 1985 in the Nanticoke River. Environmental concentrations of all toxic elements, including aluminum, were lower, pH was near neutral, and hardness and salinity were higher than in 1984 (Columbia National Fisheries Research Laboratory 1986). Since 1984, in-situ field assessments have been conducted in the Nanticoke, Choptank, Potomac, and Susquehanna Rivers, the Chesapeake and Delaware Canal, and many smaller tributaries of the upper Chesapeake Bay (Columbia National Fisheries Research Laboratory 1984, 1986; Hall et al. 1985, 1987a,b, 1988; Finger 1987, 1989). Although results of these field studies and earlier laboratory tests indicated a strong relation between the survival of larval striped bass and water quality and contaminants in the environment, extrapolation from these results to the success of striped bass reproduction in the river system for a given year requires information on water quality conditions throughout the spawning season.

The purpose of this paper is to report the results from field studies conducted in two Chesapeake Bay tributaries, the Nanticoke and Choptank Rivers, in 1989. The studies were designed to assess the survival of larval and yearling striped bass throughout the spawning season and to evaluate the water quality and contaminant conditions that existed in these tributaries during the striped bass spawning season. Locations encompassed a major portion of the spawning grounds in both rivers (Fig. 1). Three locations were selected on the Nanticoke River: upstream about 4.8 km above Vienna, Maryland; at Vienna, Maryland; and downstream about 4.0 km below Vienna, Maryland. Two locations were selected on the Choptank River: Ganeys Wharf near Harmony, Maryland; and Martinak Sate Park near Denton, Maryland. At all locations, 96-h in-situ toxicity tests were conducted April 10–14, April 21–25, April 29–May 3, and May 11–15, referred to hereafter as tests 1, 2, 3, and 4. Larvae (48 h old) were obtained from Cedarville State Hatchery, Brandywind, Maryland, for tests 1 and 2 and from Delmarva Ecological Laboratory, Middletown, Delaware, for tests 3 and 4. All larvae were spawned from Nanticoke or Choptank River females. Yearling striped bass, spawned from 1988 Choptank females, were also obtained from the Cedarville Hatchery.

Methods

General

Composite samples were deployed at each location to collect water samples at 15-min intervals throughout each day for the duration of each 4-day study. Water was pumped from the river through 0.48 cm Teflon tubing into 19-L acid-washed glass collection containers. Each container was held in an ice bath to keep the collected water cool (-4°C) during the day. Temperature, pH, dissolved oxygen, hardness, alkalinity, salinity, conductivity, and turbidity were measured daily in subsamples of the composite sample. Nitrate, nitrite, and ammonia were analyzed periodically throughout each study.

In-situ assessments were conducted at all locations on both rivers following the procedures of Hall et al. (1985). Five hundred larvae (48 h old) were tested in each of two 68-L replicate environmental chambers at each location. The chambers had four nitex (202 mesh) windows that allowed river water to flow through the chambers. Battery-powered aerators provided water movement in each chamber and minimized accumulation of silt on the nitex screens. The chambers have a permanent base that retains 5 L of water; survival was estimated daily by using a subsampling and replacement method of population estimation (Hall et al. 1985).

Survival of yearling striped bass was also assessed at all locations in the Nanticoke and Choptank rivers. Two replicates of 10 fish each were tested in 121-L in-situ chambers at each of these five locations. Survival was evaluated daily during the 14-day study.

Water quality monitoring stations were established at each of the five locations. Hydrolab DataSonde water quality monitoring units recorded hourly measurements of pH, temperature, conductivity, salinity, and dissolved oxygen continuously from 1 April to 6 June at a depth similar to that of the exposed fish.

Subsamples analyzed for organic and inorganic contaminants were collected from the composite sample. Samples filtered through 0.4-μm polycarbonate filters were collected daily from each location, acidified immediately with nitric acid, and stored for later

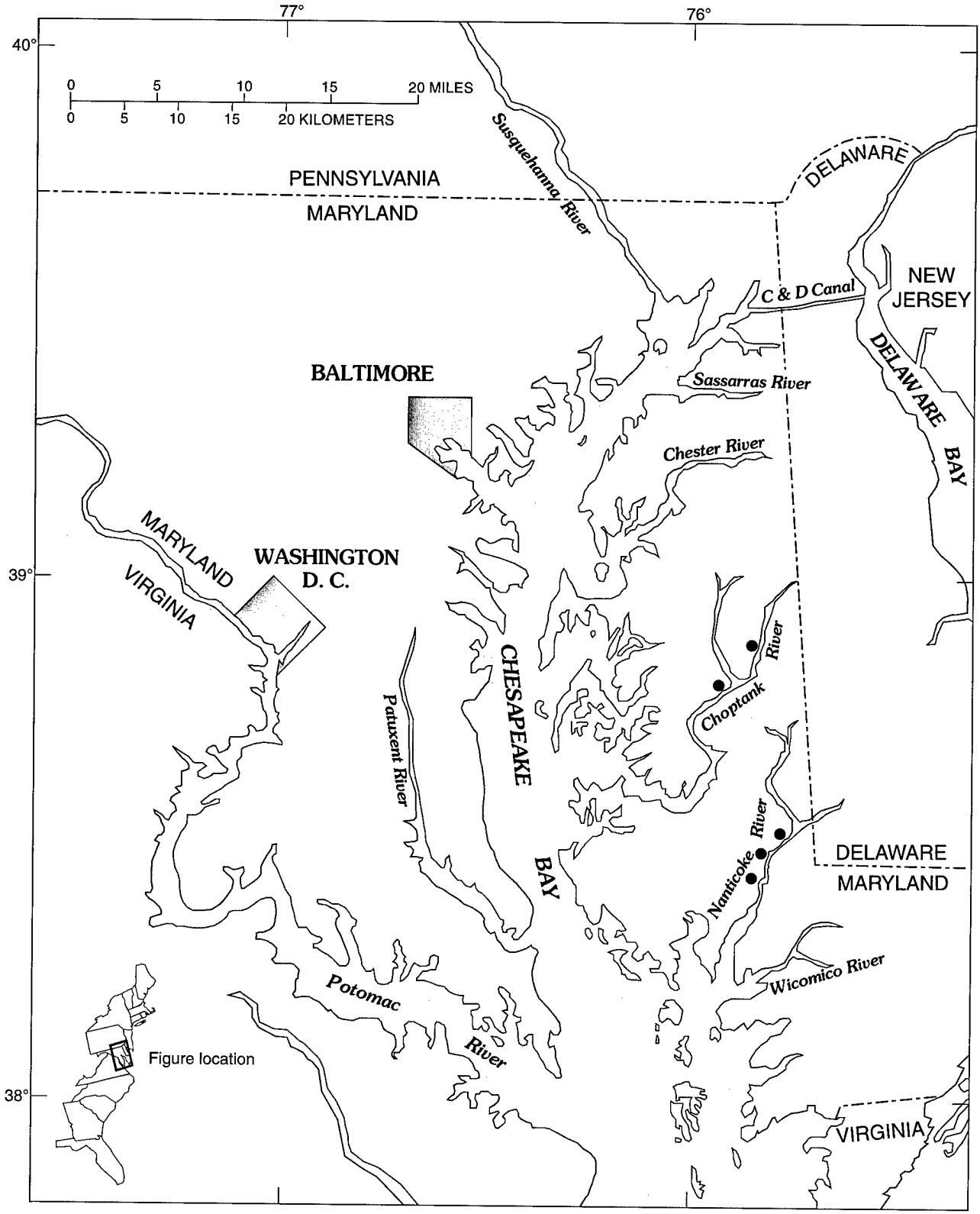

Figure 1. Map of major tributaries of Chesapeake Bay with sample locations on the Nanticoke and Choptank rivers.

inorganic analysis in acid-washed 1-L linear polyethylene bottles. In addition to daily sampling, a subsample was collected through a 0.1 μm polycarbonate filter on alternate days, extracted with methyl iso-butyl ketone (Barnes 1975), and refrigerated for later analysis of monomeric (fast-reactive) aluminum. Four-liter amber glass containers with Teflon-lined caps were used to store organic samples; residual solvents had been previously removed by washing the containers with soap and water, rinsing with deionized water and acetone, and then heating to 450°C. All samples were refrigerated at 4°C after collection.

Spiked samples prepared by NFCRC, replicate samples prepared on-site, and blanks supplied by NFCRC were included as measures of quality assurance for organic and inorganic analyses.

Chemical Analyses

Filtered water samples for inorganic contaminants were digested in 100-mL borosilicate glass beakers that had been cleaned by a 30-min concentrated nitric acid reflux cycle. About 40 mL of the sample was combined with 5 mL concentrated nitric acid and evaporated over low heat until 1 mL remained. This digestate was diluted to 50 mL with ultrapure water and analyzed for lead, cadmium, chromium, arsenic, and selenium with a Perkin Elmer Model 305-B atomic absorption spectrophotometer (AAS) equipped with an HGA-2100 graphite furnace and a deuterium arc background correction. A L'vov platform was used to reduce interferences from sample matrices (Kaiser et al. 1981). Analyses for copper and zinc were performed with a Perkin Elmer Model 603 AAS equipped with a standard air and acetylene burner, a deuterium arc background corrector, and a Model 56 recorder. The quality control matrices used for these samples were National Bureau of Standards bovine liver, albacore tuna, and oyster tissue. All results were within 20% of certified or recommended concentrations for the reference materials. Of the samples analyzed, 10% were blanks and 20% were blind replicates and spiked samples. No values for blanks exceeded detection limits for any element (Table 1).

Water samples for organochlorine pesticides and PCB's were transferred quantitatively into a 2-L glass separatory funnel with a Teflon stopcock and extracted twice with 100 mL methylene chloride. Extraction and clean-up procedures were completed as described in Environmental Protection Agency Method 608 (U.S. Office of the Federal Register 1984). The extract was concentrated to a final volume of 1.0 mL in iso-octane and analyzed by gas chromatography and electron capture detection. Quality assurance procedures included four-level standardization and analyses of reagent or method blanks and spikes in addition to all procedures listed in Method 608.

Water samples for polycyclic aromatic hydrocarbons were transferred quantitatively from the collection bottle into a 2-L glass separatory funnel and extracted twice with 100 mL of methylene chloride. Extractions and cleanup were completed according to procedures described in Method 610 (U.S. Office of the Federal Register 1984). All extracts were then combined and reduced to a final volume of 1.0 mL prior to analysis by gas chromatography and mass spectrophotometry by selective ion monitoring. The deuterated analogs of phenol, 2,4-dichlorophenol, napthalene, phenanthrene, and chrysene were used as quantitative internal standards. Quality assurance procedures included four-level standardization with 1- or 1-μl splitless-direct or cold on-column injections, reagent or method blanks, spikes, and all other quality control procedures outlined in Methods 625 and 1625 (U.S. Office of the Federal Register 1984). Detection limits for organic compounds analyzed are in Table 1.

Results

Nanticoke River

No larvae survived at any locations on the Nanticoke River during tests 1 and 2 (Table 2). Mortality of larvae was rapid and occurred within 48 h of exposure. In contrast, larvae survived at every location in test 3; most mortality occurred within 48 h, and the surviving larvae appeared to swim vigorously. In test 4, complete mortality occurred in the upstream and downstream locations, but not as rapidly as in tests 1 and 2. Survival at the Vienna location in test 4 was similar to that in test 3. No appreciable mortality of yearling striped bass occurred at any location.

River temperatures (13.0–18.0°C) increased steadily during the testing period but never represented a threat to survival of the larvae. Rainfall exceeded 6 cm during three of the four tests on the Nanticoke River (Table 2); pH of the rainwater ranged from 3.46 to 4.90. Salinity was never detected in water samples at any location, and conductivities remained less than 500 μS/cm during all four tests.

Table 1. Detection limits for inorganic elements and organic compounds

Class and compound	Detection limit
Inorganic element (μg/L)	
Lead	0.5
Cadmium	0.1
Chromium	1.0
Copper	1.0
Zinc	10.1
Arsenic	2.0
Selenium	2.0
Aluminum	1.0
Organochlorine pesticides and polychlorinated biphenyls (ng/L)	
Toxaphene	150
cis-chlordane	2
trans-chlordane	2
trans-nonachlor	2
cis-nonachlor	2
p, p' -DDE	3
p, p' -DDD	3
p, p' - DDT	3
Lindane	2
Dieldrin	2
Organochlorine pesticides and polychlorinated biphenyls (ng/L)	
Endrin	3
Pentachloroanisole	2
Aroclor 1248	150
Aroclor 1254	150
Aroclor 1260	50
Polycyclic aromatic hydrocarbons (ng/L)	
Fluorene	40
Phenanthrene	40
Anthracene	40
Fluoranthene	40
Pyrene	40
Benz(a)anthracene	40
Chrysene	40
Benz(a)pyrene	40
Perylene	40

Data from the Hydrolab DataSonde units indicated that pH was consistently low, ranging from 6.0 to 6.4 during tests 1 and 2, and never exceeded 7.0 during the spawning season. Larval survival was highest during test 3, when pH exceeded 6.5 at all three Nanticoke locations. No episodic events of low pH were recorded during any test period. In addition, neither ammonia nor nitrate was measured at environmentally significant concentrations.

Copper, zinc, and monomeric aluminum were detected in filtered water samples at higher concentrations than other inorganic elements (Table 2). Concentrations of zinc were consistent among locations and tests. With the exception of test 4, highest levels of copper and aluminum corresponded to times of highest rainfall and lowest pH. During test 4, although pH and rainfall were similar among locations, levels of aluminum upstream and downstream from Vienna were more than twice as high as concentrations at Vienna. This difference may account for the higher survival observed at Vienna during this test. Low levels of lead, nickel, chromium, arsenic, and selenium were measured in water samples from all locations. No organic compounds were detected in any samples.

Table 2. Percent mortality of larval striped bass after 96 h in four experiments conducted at three locations on the Nanticoke River near Vienna, Maryland, in spring 1989

[Total rainfall and ranges in pH and concentrations of metals are reported for each experiment. No salinity was detected during any test. River temperatures ranged from 13.0 to 18.0°C during testing.

Site and experiment number	Mortality (percent)	pH	Metals (μg/L)			Rain (cm)
			Al	Cu	Zn	
Upstream						
1	100	6.0–6.2	85–148	8–29	24–76	10.2
2	100	6.1–6.3	93–99	12–18	25–64	8.8
3	72	6.5–6.7	17–35	7–9	22–38	2.1
4	100	6.3–6.4	79–150	9–15	29–82	8.5
Vienna						
1	100	6.1–6.3	105–154	3–19	19–62	12.4
2	100	6.0–6.4	95–117	9–19	28–61	9.2
3	68	6.7–6.9	43–57	4–7	32–49	1.0
4	66	6.4–6.6	25–38	4–9	22–56	6.1
Downstream						
1	100	6.1–6.3	100–168	12–20	33–65	10.7
2	100	6.0–6.3	81–177	9–14	39–72	7.4
3	63	6.7–6.8	36–47	3–7	26–64	0
4	100	6.4–6.6	79–98	4–9	45–79	7.0

Choptank River

Mortality of larvae in the Choptank River was similar to that in the Nanticoke River. No larvae survived tests at any locations on the Choptank River during tests 1, 2, or 4 (Table 3). Mortality was rapid in tests 1 and 2 and occurred within 48 h of exposure, but it was more gradual in test 4. Larvae survived at every location in test 3, but survival was lower than that observed in Nanticoke tests. Again, no appreciable mortality occurred in yearling fish.

Amount of precipitation and water quality were similar to those measured for the Nanticoke River (Table 3). River temperatures (13.0–17.6°C) remained within tolerance limits for striped bass larvae. Salinity was never detected in water samples at any location, and conductivities remained less than 350 μS/cm during all four studies. Information collected with the Hydrolab DataSonde water quality monitoring units indicated that pH was consistently low (6.0 to 6.4) during tests 1, 2, and 4. No episodic events of low pH occurred during the test periods. Larval survival was highest during test 3, when pH was slightly higher than that measured in other tests (Table 3). Levels of pH increased to consistently higher levels (6.6 to 6.9) after 15 May but did not reach 7.0 until 2 June. No environmentally significant levels of ammonia or nitrate were measured in the river during our tests.

Concentrations of copper, zinc, cadmium, and aluminum detected in filtered water samples were higher than those of other inorganic elements. Concentrations of zinc were constant among locations and tests, but highest levels of cadmium, copper, and aluminum corresponded to the periods of highest rainfall (Table 3). Aluminum concentrations were consistently lower than those measured in the Nanticoke River. Low levels of lead, nickel, chromium, arsenic, and selenium were also measured in water samples from all Choptank locations. No organic compounds were detected in any samples.

Table 3. Percent mortality of larval striped bass after 96 h in four experiments conducted at two locations on the Choptank River in spring 1989

[Total rainfall and ranges in pH and concentrations of metals are reported for each experiment. No salinity was detected during any test. River temperatures ranged from 13.0 to 17.6°C during testing.

Site and experiment number	Mortality (percent)	pH	Metals (μg/L) Al	Cu	Zn	Cd	Rain (cm)
Martinak							
1	100	6.0–6.2	17–28	9–23	21–60	10–23	12.9
2	100	6.1–6.3	25–49	7–18	23–57	9–16	9.5
3	87	6.4–6.6	14–23	6–11	24–39	5–8	0.5
4	100	6.1–6.4	23–56	9–15	28–64	12–18	10.1
Ganeys Wharf							
1	100	6.1–6.3	10–22	7–17	29–60	12–19	11.4
2	100	6.0–6.1	19–28	6–10	32–71	8–16	7.2
3	89	6.3–6.6	9–15	5–8	22–63	8–11	0.8
4	100	6.0–6.3	19–24	7–13	19–35	10–18	11.9

Discussion

Chesapeake Bay is one of the largest, most productive estuarine systems in the world, but changes since the 1950's have contributed to its ecological decline (U.S. Environmental Protection Agency 1983). In addition to the declines in striped bass populations, alewife (*Alosa pseudoharenqus*), American shad (*Alosa sapidissima*), oysters (*Crassostrea virginicia*), clams (*Mercenaria mercenaria*, *Rangia cuneata*), and submerged aquatic vegetation have also decreased. There is also evidence of nutrient enrichment, anoxic conditions, and the presence of elevated concentrations of heavy metals and toxic organic contaminants. Chesapeake Bay is showing distinct changes related to increased human activity and alterations in land-use patterns. Percentage of land in urban use has almost doubled since 1950, and cropland and pasture have decreased significantly (U.S. Environmental Protection Agency 1983). The population in this area increased by 4.2 million between 1950 and 1980, and an additional increase of 1.9 million people is anticipated by the year 2000 (U.S. Environmental Protection Agency 1983). Increases in urbanization and population densities place additional stresses on the Chesapeake Bay basin because of increased demands for freshwater and larger amounts of waste from sewage, urban runoff, and industrial activity.

Increased organic and inorganic contamination from point and nonpoint source pollution in the Chesapeake system and the excessive fishing mortality of striped bass during the 1970's are now considered as the major contributors to the decline of the species. Determining the relative importance of these sources of mortality is difficult (Klauda and Bender 1987). The collapse of commercial or sport fisheries from overfishing alone or from a combination of overfishing and increased pollution has been demonstrated; however, there is no direct evidence to document a decline of a fishery caused by pollution alone (Wohlfarth 1986). Nonetheless, mortality of striped bass larvae has been related to water quality conditions and the presence of contaminants in spawning and nursery areas in the Nanticoke and Choptank Rivers (Columbia National Fisheries Research Laboratory 1984, 1986; Hall et al. 1985, 1988; Finger 1987, 1989), in the Potomac River (Columbia National Fisheries Research Laboratory 1986; Hall et al.1987a), and in tributaries of the Upper Bay (Hall et al. 1988). Conclusions from these field studies have been supported by laboratory tests demonstrating the toxicity of mixtures of contaminants at levels similar to those measured in Chesapeake Bay tributaries.

Tributaries such as the Nanticoke and Choptank Rivers, with soft, poorly buffered water, are more suspectable to acidification than is the Potomac River (Hall et al. 1987a) or the Chesapeake and Delaware Canal (Columbia National Fisheries Research Laboratory 1986; Hall et al. 1987b). Our field studies and laboratory studies by Buckler et al. (1987) indicated that low pH can significantly decrease the survival of larvae and increase the toxicity of contaminants to striped bass larvae. Although no long-term trends of increasing stream acidity have been identified in the Chesapeake region, episodic events of low pH have been documented in several Chesapeake streams (Bowman 1984; Janicki et al. 1986), including the Nanticoke River (Finger 1989), and such events can severely stress larval finfish.

Results from our study on the Nanticoke and Choptank Rivers further substantiate the importance of contaminants in striped bass survival. Survival was poor in all 20 tests, but mortality was highest during periods when pH was low (6.0 to 6.4), no salinity was detected, and concentrations of aluminum and copper were elevated. Concentrations of cadmium in the Choptank River were higher than those measured in previous studies in this river (Hall et al. 1988; Finger 1989) and exceeded levels believed to be acutely toxic to aquatic organisms (U.S. Environmental Protection Agency 1985). In addition, other inorganic contaminants at concentrations similar to those tested in laboratory mixtures were present in both rivers. Although the relative importance of fishing mortality and contaminant impacts has not been established, the persistence of poor water quality and contaminant conditions in spawning areas may inhibit the recovery of striped bass populations, regardless of the intensity of fishing pressure.

Acknowledgments

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Salmon and Steelhead Restoration and Management on the Columbia River

by

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Abstract. During the past 20 years, salmon (*Oncorhynchus* spp.) and steelhead (*O. mykiss*) management in the Pacific Northwest has been plagued by bitter conflict and litigation. In recent years, however, anadromous fish-producing states, the 24 Indian tribes with treaty fishing rights, and the Federal Government have worked cooperatively to manage these resources.

Successful salmon and steelhead management is vitally important to the economy of the Pacific Northwest. In 1986, the commercial salmon harvest in Washington (including Puget Sound), Oregon, and California was over 7.1 million fish, with a value estimated at over $230 million. The most recent figures available for sport fishing show that in 1986, sports men and women caught 460,000 chinook (*O. tshawytscha*) and 480,000 coho (*O. kisutch*) valued at $107 million. In addition, the treaty Indian net fishery on the Columbia River yielded another 138,000 chinook and coho salmon. Further, most salmon produced in the Columbia River basin and along the Washington coast migrate northward, and many are caught in British Columbia and Alaska fisheries, providing significant contribution to the economies of these areas. Non-consumptive use of salmon and steelhead is also important for the economy and quality of life in the Pacific Northwest. Many areas and facilities for viewing salmon and steelhead are located close to major population centers and are important tourist attractions. Public use of these areas has increased significantly in recent years.

The U.S. Fish and Wildlife Service (Service) is an integral part of a closely coordinated interagency network involved with management and restoration of the Pacific salmon and steelhead fishery resources in the Pacific Northwest. The Service's program is one of over 20 resource agency programs that share

responsibility for the production and management of salmon and steelhead in the Pacific Northwest. The Service has mandated responsibilities for fisheries mitigation and restoration that are clearly defined in legislation and interagency agreements and by a comprehensive statement of its responsibilities and role. Through these mandates the Service is playing a vital part in implementing domestic and international treaties and producing fish for sport and commercial harvest and nonconsumptive uses.

The Service's fisheries program in the Pacific Northwest consists of restoring and mitigating for salmon and steelhead losses as a result of federal power and water development projects and land use practices. Fish lost as a result of federal actions are replaced by hatchery production and habitat protection and rehabilitation to improve natural production. In 1986, over 60 million juvenile fish, expected to contribute 700,000 adults to sport and commercial fisheries, were produced in a network of 18 national fish hatcheries. These hatcheries have net capital improvement valued at over $265 million.

In addition to replacing fish lost to direct federal actions, there are eight Fisheries Assistance and River Coordinator offices that coordinate hatchery production with other agencies, evaluate production success, and work toward restoring natural-spawning fish populations through cooperative interagency activities. Similarly, four Fish Health centers work closely with hatcheries, the Seattle Research Center, and Fisheries Assistance offices to maximize survival of young fish by ensuring these fish are as healthy as possible before release. An internationally recognized Salmon Culture Technology Center provides direct technical and operational support to Fish and Wildlife Service hatchery operations and to state, tribal, Canadian, and private hatcheries. The Center's contributions have significantly enhanced survival of hatchery fish through nutritional studies, diet analysis, and hatchery production improvements.

Salmon and Steelhead Management in the Columbia River

The Columbia River is the second largest river in the United States measured in volume runoff. The river drains an area of 416,808 k^2, which includes major portions of the states of Washington, Oregon, and Idaho and parts of Montana, Wyoming, Nevada, and Utah, as well as the Canadian provinces of British Columbia and Alberta.

Prior to development, the Columbia River Basin produced an estimated 10 to 16 million adult salmon and steelhead each year from 23,657 k^2 of habitat. Currently the basin produces 2.5 to 3.0 million salmon and steelhead. The loss of 7–14 million fish was due primarily to the effects of hydropower development operation (5–11 million fish), but other activities have also contributed to the loss (2–3 million fish), including agriculture, mining, logging, and overfishing.

Hydropower development in the basin has been extensive. The 136 hydropower projects in the basin, which produce about 70% of the electricity used in the Pacific Northwest, have altered natural flow patterns and blocked access to much of the prime spawning and rearing habitat. About 35% of the historical spawning and rearing habitat in the upper basin is no longer accessible because of the construction of dams such as Grand Coulee Dam on the upper Columbia River and Brownlee Dam on the Snake River. Providing access to these blocked areas is a difficult problem because the juvenile fish cannot find their way downstream through the large reservoirs behind the high dams.

While high dams have blocked access, low-head dams on the mainstem of the Columbia and Snake Rivers have created a gauntlet the juvenile fish must pass on their way to the ocean and adults must pass during upstream migration. Juvenile salmon and steelhead migrating out of the remaining accessible habitat in the Snake River have to pass up to eight dams and those from the upper Columbia River up to nine dams during their journey to the ocean, where they feed until returning on their spawning migration. Research has shown that between 6% and 32% of the juvenile salmon and steelhead passing through the turbines are killed at each dam. On average 5% to 10% of the returning adult fish are lost per dam during their upstream migration.

The large reservoirs behind the dams also create ideal habitat for predators such as northern sqawfish, and they delay the juvenile migration because the water velocities are slower. Fish that are delayed in the reservoirs are more exposed to predation, and if delayed long enough they will lose their urge to migrate and take up residence in the reservoirs. The cumulative effect of all of the dams and reservoirs can be devastating. For example, in the extremely low flow years of 1973 and 1977, 95% of the juvenile spring chinook salmon migrating out of the Snake River were lost.

By 1975, returns of salmon and steelhead were significantly lower than historic runs, particularly for Snake River runs (Fig. 1) and several runs were considered for listing as threatened or endangered under the federal Endangered Species Act. The decline of the fish runs in the Columbia River due to hydropower development eventually led to passage of federal legislation, the Pacific Northwest Electric Power Planning and Conservation Act of 1980 (Power Act), which included provisions for equitable treatment of fish and wildlife in the management of the hydropower system. The Power Act also provided for funding of fish and wildlife restoration through the use of hydropower revenues from the Bonneville Power Administration (BPA), which is the federal agency responsible for marketing the power generated by the Federal Columbia River Hydropower System. The Power Act established the Northwest Power Planning Council, which is an interstate compact created by Idaho, Washington, Oregon, and Montana. Each state has two council members.

The Power Act directed the Council to develop a Fish and Wildlife Program for replacing fish and wildlife losses due to hydropower development, as well as a power plan for developing the energy resources of the region. About $35 million is being spent annually to implement this program. While some stocks of fish show signs of improvement, much work needs to be done.

Correcting problems with mainstem passage has been identified by the fish and wildlife agencies and Indian tribes as the highest priority under the council's Fish and Wildlife Program. Reducing the loss as the juvenile and adult fish run the gauntlet of dams is a key to rebuilding natural production of salmon and steelhead in the upper river and is essential to improving the effectiveness of the large state, federal, and utility industry investment to hatchery production.

Several techniques have been employed to help juvenile fish pass safely downstream to the ocean. In the 1970's the technology was developed to screen the intakes to the turbines at the dams and guide the young salmon and steelhead up through the gatewell, through orifices into a transportation channel, and safely in the tailrace of the dam (Fig. 2). The council has adopted installation of bypass facilities as the long-term solution to the fish losses occurring at the dams. However, effective bypass facilities have been installed in only 6 of the 13 mainstem dams. The council has been building a broad-based consensus among the hydropower operators, Bonneville Power Administration, public and private utilities, fish and wildlife agencies, Indian tribes, and the Northwest Congressional Delegation to accelerate the bypass program, but the bypass system will not be completed at the remaining dams until the late 1990's.

In the interim, passing the juvenile fish by spilling water at the dams is the most effective means to reduce the mortality. Only 1% of the fish passing over the spillway are killed compared with 6% to 32% in the turbines. However, spilling water is expensive because of the energy generation foregone, and less and less spill is available each year because of the installation of new generating units and the expanded capacity to send electricity to the southwestern United States. After 1.5 years of negotiations an agreement was signed in 1989, between the fishery managers and the hydropower interests, establishing how much water will be spilled to protect fish at the dams. The Fish Spill Memorandum of Agreement establishes the amount of water to be spilled at each of the federal dams and is an effective interim protection measure that will aid in rebuilding fish runs in the river.

Another problem created by hydropower development is the alteration of the natural flow pattern. Much of the spring runoff, which is important for moving the juvenile salmon and steelhead down the river to the ocean, is now stored and released during low flow periods to generate electricity.

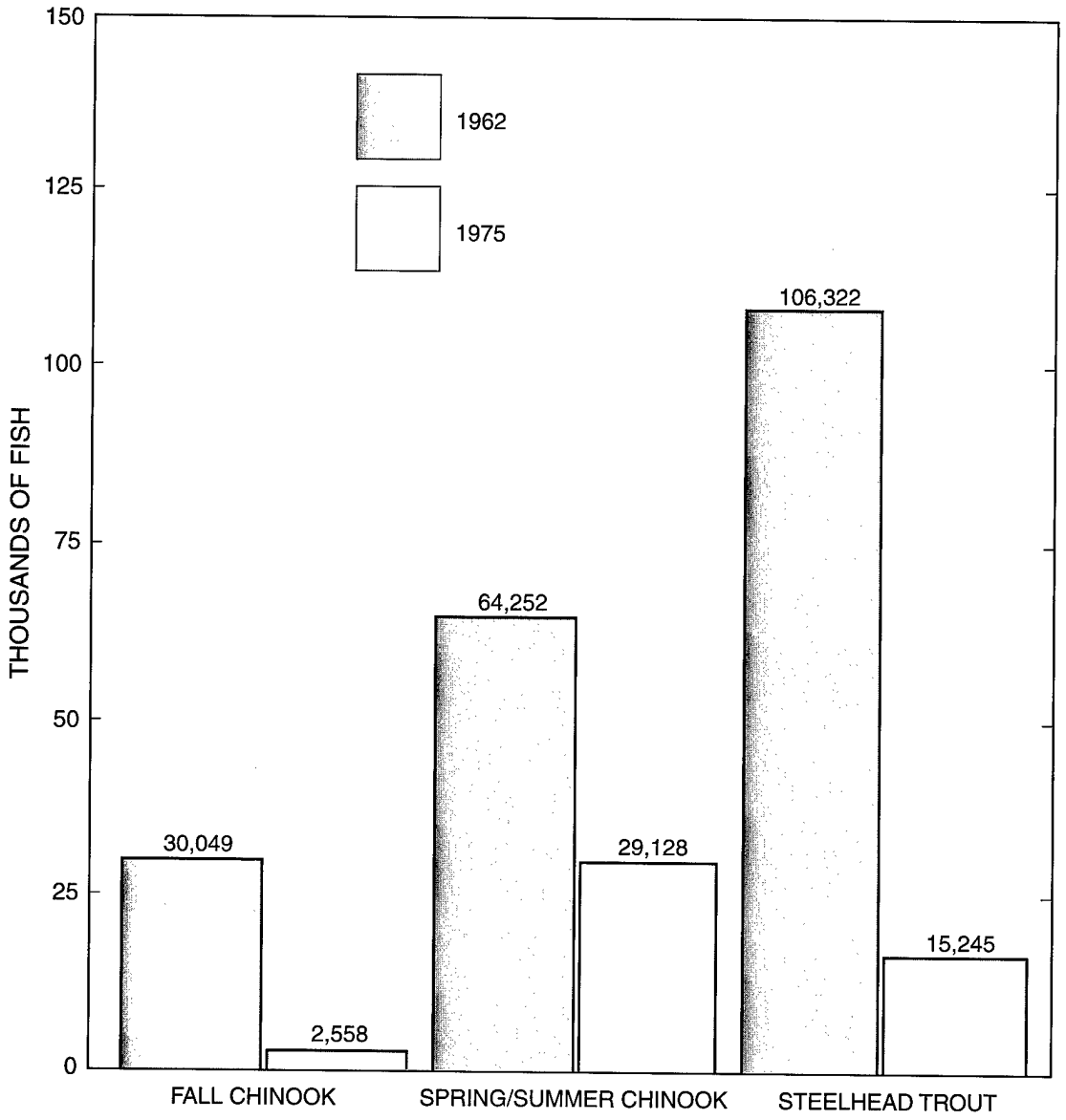

Figure 1. Comparison of the migration of chinook salmon and steelhead passing Ice Harbor Dam, Lower Snake River, Washington, between 1962 and 1975.

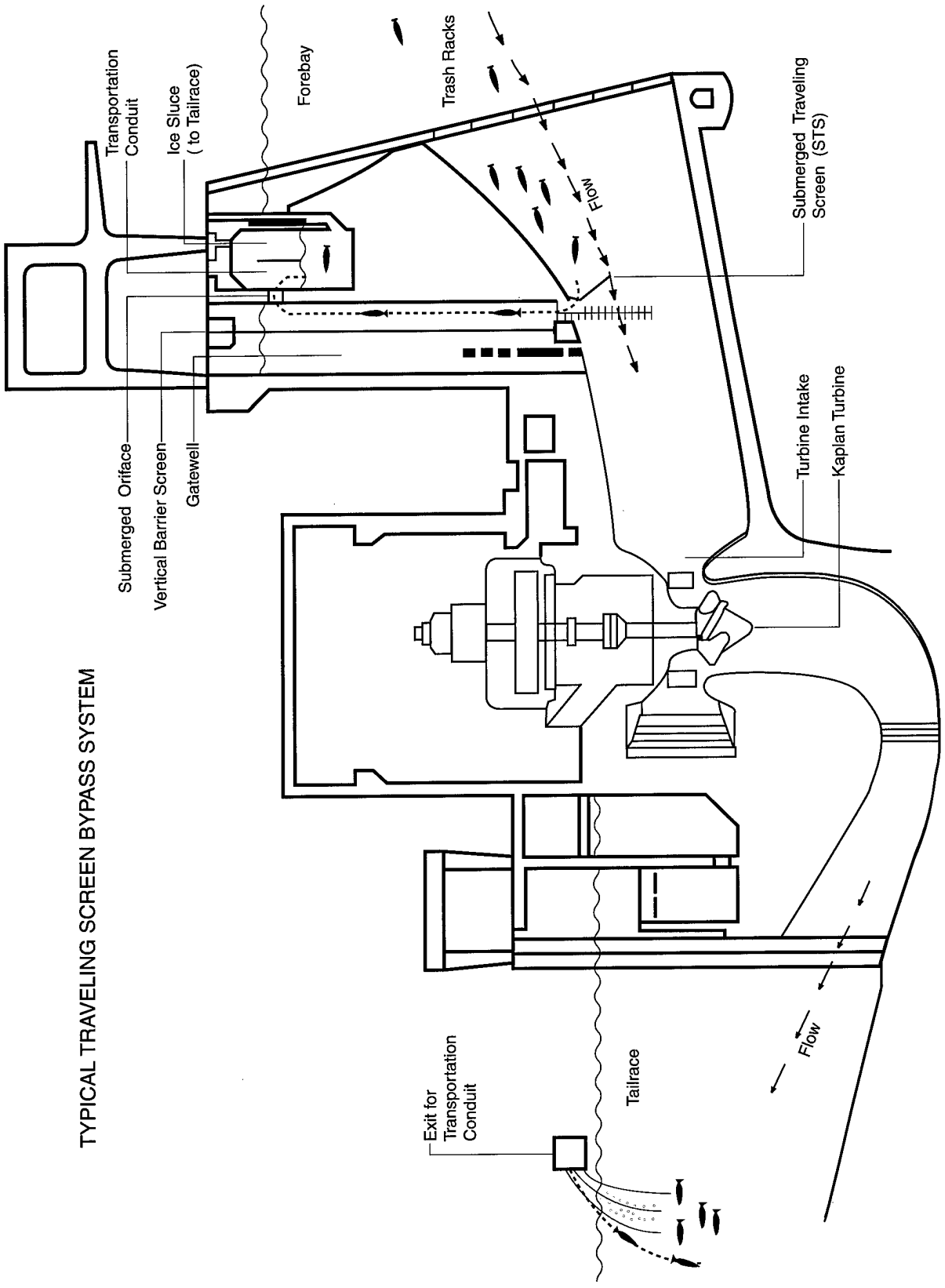

Figure 2. Transverse section of a dam showing the location of the traveling screen, gatewell, and route for fish to the tailrace.

The regulated river flow is substantially lower than the historic flows during May, June, July, and August, when most of the juvenile fish migrate (Fig. 3). As stated earlier, many fish die in the reservoirs during low flows because of predation and other causes. The council attempted to solve this problem by setting aside a block of water called the water budget which could be used by the fish and wildlife agencies and Indian tribes to increase spring flows to aid downstream migration. The concept has been in effect for about 5 years but major problems have been encountered.

1. The water budget can only be used from 15 April to 15 June. There are no means to augment flows after 15 June, when substantial numbers of fish are migrating downstream, and adult fish are migrating upstream.
2. The size of the water budget is inadequate, particularly in the Snake River. In recent years fish and wildlife managers have only been able to augment flows in the Snake River for about a 10-day period before the water budget runs out. This is inadequate to move the fish safely down the system and provide protection for adult fish.

Negotiations are underway in an attempt to provide adequate flows for salmon and steelhead.

The fish and wildlife agencies and Indian tribes are also working with the U.S. Army Corps of Engineers to improve the collection and transport of juvenile fish around the dams. Collection and transport facilities are currently located at three dams. The juvenile fish are collected at the dam by the bypass facility and are either loaded into a barge or truck. The barges or trucks transport the fish to below Bonneville Dam for release.

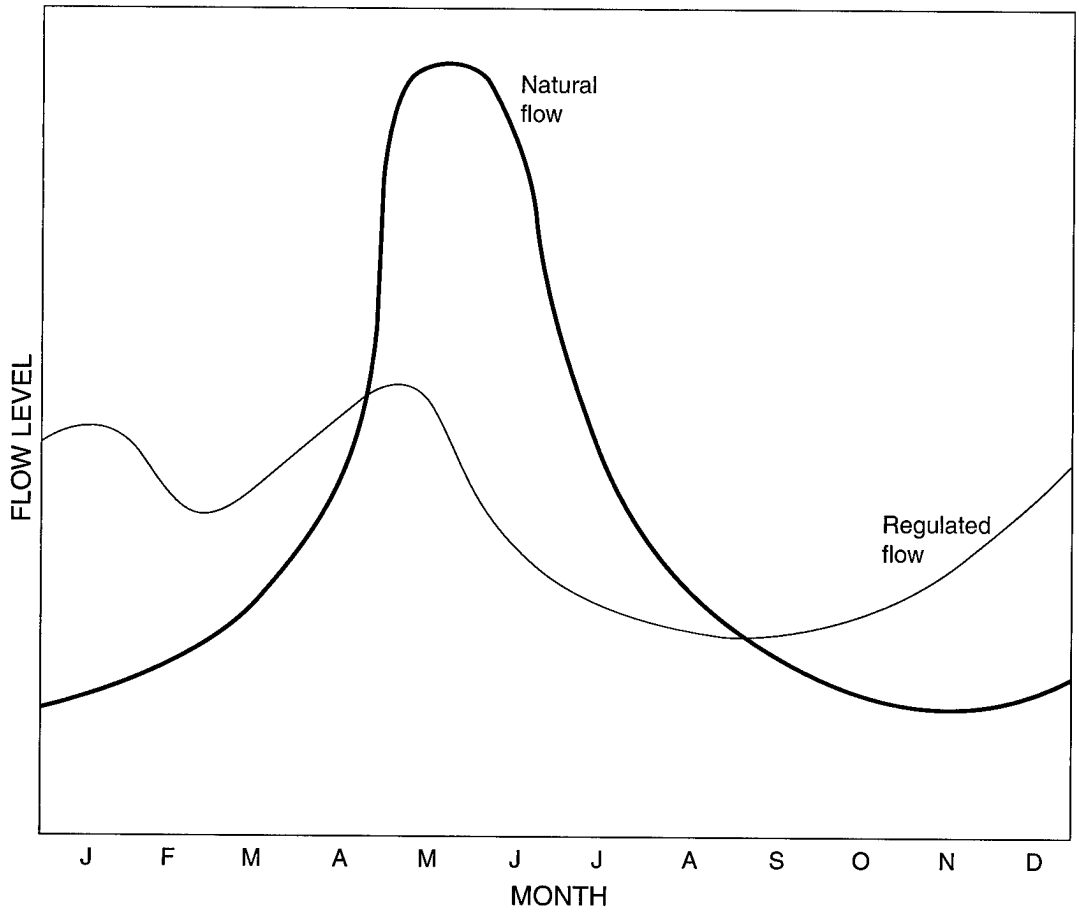

Figure 3. Natural and regulated flows in the Columbia River System.

About 20 million juvenile salmon and steelhead are collected and transported each year. Transportation has been very effective in improving survival of steelhead and fall chinook, but not very effective for spring chinook. This technique is not viewed as an alternative to installing bypass facilities or improving flows. Many juvenile fish are not intercepted at the dams because they enter the river below the collection facilities and must be protected by other means.

Efforts to improve mainstem passage will go a long way toward helping to rebuild the runs but cannot compensate for the significant amounts of lost habitat that are inaccessible. The council has set an interim goal of increasing the run sized by 2.5 million adult fish. Hatcheries will play a major role in meeting this goal. At the same time the fisheries managers are committed to rebuilding wild populations and maintaining the genetic diversity of all stocks in the basin. A comprehensive basinwide fish management planning effort is underway to carefully integrate hatchery production and natural production to achieve the proper balance between the two.

At present there are 64 hatcheries and 29 associated facilities (acclimation ponds, release sites) in the basin that rear and release 150–200 million juvenile salmon and steelhead each year. Hatchery production supports about 2.0 million of the current production of 2.5–3.0 million adult salmon and steelhead each year from the Columbia River Basin.

Management Coordination on the Columbia River

Coordination of the fishery management efforts in the Columbia River Basin is complex. Twenty fish and wildlife agencies and Indian tribes have management jurisdiction over salmon and steelhead, while other agencies control the river's flow through the operation and management of the hydropower system. Several land management agencies have jurisdiction over much of the habitat in the basin. Competing demands for the water and for the fish have created much controversy and litigation.

The Power Act provides a means, through program coordination and funding, to balance hydropower and fish and wildlife populations. In 1987, the fish and wildlife agencies and tribes in the basin established an association of state and federal fish and wildlife agencies and Indian tribes to facilitate interagency and tribal involvement in implementing the council's Fish and Wildlife Program. The association, the Columbia Basin Fish and Wildlife Authority, provides a forum for exchanging information among its 20 members and for developing consensus positions on implementation of the Fish and Wildlife Program. The authority interacts with the water and land management authorities of the basin, but it does not coordinate harvest management for salmon and steelhead in the Columbia River basin. Harvest management is under the continuing jurisdiction of the U.S. District Court.

The U.S. District Court directed the parties under *U.S.* v. *Oregon* to settle litigation over harvest and production of Columbia River salmon and steelhead. The Columbia River Fish Management Plan was completed in 1988 after 5 years of negotiations and was approved by the court. The plan provides a framework for the fish and wildlife agencies and Indian tribes to exercise their fishery management authorities in a coordinated and systematic manner to rebuild the fish runs in the basin and provide for fair sharing of the harvest. Coupled with harvest management of the ocean fisheries under the Magnuson Fishery Conservation and Management Act and the Pacific Salmon Treaty, the plan provides the final link in harvest management of the wide-ranging stocks of salmon and steelhead produced in the Columbia River basin.

After over 50 years of management of the river primarily for maximizing hydropower benefits, the transition to more equitable treatment for fish and wildlife is showing some progress. Progress will continue to be made as long as each interest group is willing to continue to discuss issues in an objective manner and is willing to work toward solutions to problems. An effective cooperative framework for comanagement of the Columbia River is in place and will continue to facilitate restoration of salmon and steelhead.

Gulf of Mexico Sturgeon (Acipenser oxyrhynchus desotoi) in the Suwannee River, Florida

by

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Abstract. The Gulf of Mexico sturgeon (*Acipenser oxyrhynchus desotoi*), a subspecies of the Atlantic sturgeon (*A. oxyrhynchus*), was widely distributed throughout the coastal rivers of the Gulf of Mexico but has declined because of loss of suitable freshwater habitat and overexploitation by commercial fishermen. The Suwannee River, Florida, seems to support the largest and possibly only remaining viable spawning population of this subspecies. The Gulf of Mexico sturgeon is a candidate species for listing as threatened under the Endangered Species Act. The decline of this sturgeon prompted the U.S. Fish and Wildlife Service to begin studies in 1987 to determine its early life history, food habits, movement, and seasonal abundance in the Suwannee River. A major responsibility of the Fish and Wildlife Service is the restoration of depleted anadromous species.

To estimate sturgeon seasonal abundance throughout the Suwannee River, gill netting with meshes of various sizes began in March 1988 at the river mouth and at seven other sites dispersed on the lower 200 km of river. Through December 1989, 332 juvenile sturgeon were collected. Most sturgeon were weighed, measured, marked with external anchor tags and internal passive integrated transponders, and released at site of capture. Marking is to provide growth and movement information and assist in population size estimation. Twenty-six sturgeon ranging in size from 2.5 to 72.6 kg were equipped with temperature-sensing ratio transmitters to determine diet and seasonal movement, preferred water temperatures, and spawning areas. Some sturgeon were harvested seasonally as part of a study to assess benthic invertebrate food resources and feeding preferences. Field work is in cooperation with the Caribbean Conservation Corporation, a private nonprofit research organization. The corporation's research is aimed at estimating the number of adult sturgeon entering the river each spring. Center researchers are also helping other Fish and Wildlife Service sections and the corporation to spawn sturgeon artificially at temporary hatchery facilities near the mouth of the Suwannee River. Gulf of Mexico sturgeon were first spawned successfully using artificial means in March 1989. Spawning techniques developed will assist in restoration efforts in other selected Gulf of Mexico rivers.

Addendum

The gulf sturgeon was listed as "threatened" under the Endangered Species Act effective 30 October 1991. Publications resulting from the described research are:

Foster, A. M. 1993. Movement of Gulf sturgeon, *Acipenser oxyrhynchus desotoi*, in the Suwannee River, Florida. M.S. thesis, University of Florida, Gainesville. 130 pp.

Mason, W. T., Jr., and J. P. Clugston. 1993. Foods of the Gulf sturgeon in the Suwannee River, Florida. Transactions of the American Fisheries Society 122:378–385.

Mason, W. T., Jr., J. P. Clugston, and A. M. Foster. 1992. Growth of laboratory held Gulf of Mexico sturgeon *Acipenser oxyrhynchus destoi*. Progressive Fish-Culturist 54:59–61.

Genetic Considerations in Fish-Cultural Practices

by

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Abstract. Managers of Columbia River fisheries intend to use hatcheries to increase the number of fish produced in natural habitats without disrupting the productive capacity (fitness) of the basin's remaining native stocks. Genetic change in native populations, brought about by contact with hatchery fish, probably is inevitable. Disruption in their fitness, however, may be minimized by using locally adapted brood fish in hatcheries, avoiding artificial selection except as needed to maintain adaptive traits, maintaining high effective breeding numbers, and eliminating, to the extent possible, the straying of hatchery fish into native populations.

Hatcheries are an indispensable part of the fish production system for anadromous salmonids in the western United States. Many were built to compensate for lost fish production when rivers were dammed for electric power generation, flood control, and irrigation.

After initial failures, fish culturists have found the release of fish as smolts to be the most successful technique. When smolts are released at the hatchery, at a size and physiological condition that predisposes them for immediate emigration to the ocean, the adults return directly to the hatchery. Presumably, little interference with native populations results from such smolt culture programs. Some returning fish stray onto natural spawning areas, but the general perception has been that the interaction with native stocks is insignificant.

This concept of hatchery operation is changing, however, to encompass the use of hatchery fish to supplement natural spawning. Such supplementation is believed appropriate when native populations fall below levels necessary for maximum smolt production. Potential genetic problems with the development and implementation of this use of hatcheries are the subject of this discussion.

The terms "stock" and "locally adapted population" are used interchangeable. "Population" refers to any defined group of individuals.

Management Goals

Resource planners and managers (Northwest Power Planning Council 1987) intend to supplement depressed populations of anadromous salmonids in the Columbia River basin with hatchery fish, while protecting the gene resources and fitness of native stocks. Research shows, however, that hatchery fish adapt to an environment defined in part by early hatchery experience (Reisenbichler and McIntyre 1977; Altukhov and Salmenkova 1981; Chilcote et al. 1986; Nickelson et al. 1986). Consequently, supplementation can result in gene flow between differentially adapted hatchery and native stocks, risking the fitness of both.

In an intensively managed river basin (e.g., the Columbia River watershed), preservation of the historic character of fish genetic systems is an unreasonable expectation. Instead, goals to protect the fitness of these resources should be advanced. "Fitness," the measure of a population's capacity for survival and subsequent reproduction, is a consequence of

local adaptation and is thus closely associated with genetic differences among stocks. These differences manifest themselves not only in between-stock variability in gene frequencies but also in the organizational structure of genes within stocks (i.e., co-adapted gene complexes; Templeton 1986). Accordingly, to protect the fitness of anadromous salmonids, managers need to maintain genetic variability between stocks and integrity of genetic material within stocks.

Local Adaptation and Outbreeding Depression

A first step in protecting fitness of anadromous fish is that of identifying, among the fish of a basin, the aggregations to be considered as separate units for conservation management purposes. Once a classification system is in place, steps can be taken to ensure that fish in each unit are protected from unwarranted interference by fish from other units. Brood stock for hatchery fish to be used in a unit would consist of adults that originated from young produced in the same unit.

Anadromous salmonids from adjacent tributaries of the same river sometimes have significant site-specific adaptations (Wade 1987). Unfortunately, the effort and time required for an exhaustive survey of these adaptations would be great, and the results are likely to be inconclusive. Indirect definitions of stocks based on, for example, biochemical, morphological, and physiological types in populations have been described, but none has provided a basis with sufficient detail for separating individual breeding units and for describing the relations among groups. Gene frequencies determined from biochemical variants, for example, do not permit separation of some groups that have significant differences in habitat preferences and life histories (e.g., summer and winter races of steelhead, *Oncorhynchus mykiss*; Reisenbichler and Phelps 1989). Given the limitations of technology, an alternative system for classification must be devised, based on workable, objectively defined criteria.

The basin or subbasin in which an anadromous species lives might provide a useful basis for such classification. Populations could be defined on the basis of stream order. The smallest permanent streams are Order 1. Order 2 streams are formed by the confluence of two Order 1 streams, and so forth, up to maximum orders of 7 or 8 for the mainstems of large rivers. Managers could use this system to decide at what level (stream order) they choose to protect local adaptations. At a 1:500,000 scale, for example, about 36 Order 4, and 146 Order 3 streams (data of the Northwest Power Planning Council) are in the Columbia River basin. Populations so defined are likely to include what previously was considered several smaller stocks, and combining small stocks into a single layer population for management as a single "genetic unit" may reduce fitness of the species in the basin. That is, some loss of fitness may be an inevitable result of this crude classification scheme. In the absence of such management units, however, the existing practice of regularly transferring fish from area to area within a basin is likely to cause much greater disruptions in fitness.

Given the uncertainty about the basis for local adaptations and the geographic area over which they are important, a conservative program is in order. Management schemes to protect supplemented native populations should provide for protection of as many stocks (or aggregations that will be treated as stocks) in as many geographic areas as possible. Neither hatchery stocks nor native stocks should be transferred across the boundaries established for stock definition.

Transfer of coho salmon (*O. kisutch*) to locations other than their home stream results in reduced survivorship (Reisenbichler 1988). Survival of F_1 generation hybrids also dropped as genetic differences in parents, measured by relative survival of the transferred parental stock, increased (R.R. Reisenbichler, unpublished data). Why should this be and what about subsequent generations? Fitness can be disrupted in offspring from matings of stocks that differ in the interactive structure of their genes; their "co-adapted" complexes exist because their genes are selected for *joint effects* on fitness (Falconer 1981). Part of the importance of coadapted genes to the present discussion is the apparent disruption that occurs when two locally adapted stocks interbreed. Although favorable epistatic combinations may occur in the first generation from such crosses, these are generally lost due to segregation in later generations. Viability in the F_2 was reduced in 19 of 22 crosses between locally adapted populations in a variety of animal species (Endler 1977). Thus depression of fitness due to mixing stocks arises not only because of differences in traits adapting each stock to a locale but also as a consequence of disrupting the interactive patterns of gene action within each individual stock.

Hatchery Brood Stock Management

The gene pool of a hatchery-supplemented stock will be least disrupted if the hatchery fish are offspring of the native or wild population. The risk of disruption is greatest when the hatchery fish are the progeny of fish adapted to a hatchery. The expected effect from interbreeding increases with the number of generations that hatchery fish have been used as brood stock. Fish adapted to hatchery conditions should be used only when it is impossible to obtain enough brood fish from the natural population.

Selection for the hatchery program, either intentional or unintentional, can occur at any stage in the life cycle and result in genetic change and perhaps loss of genetic material. Retention in a hatchery population of only spawners possessing a desired trait, such as large body size, is an example of intentional selection. Unintentional selection can result from any source of mortality. The effects of selection cannot accumulate in anadromous salmonids produced in hatcheries where the adults used to produce each brood are captured from a large run of wild fish but will accumulate where hatchery fish beget hatchery fish. Because selection for hatchery conditions is counterproductive in the culture of fish for supplementation, and because supplementation will replace fish in endemic stocks with hatchery fish, there is no justification for intentional selective breeding in hatchery programs unless it is done to overcome nonrandom effects (e.g. harvest effects) caused by man.

The potential for deleterious effects of small population size in a hatchery brood (inbreeding and genetic drift) is not expected to be significant when hatchery fish are only a small part of the supplemented population. In situations where hatchery fish are a large part of the total population, however, care must be taken to ensure that the effective breeding number is sufficient to preclude the deleterious effects of small population size (Falconer 1981; Tave 1986). Culturists should use breeding schemes that will keep the effective breeding number as high as possible in any hatchery producing fish to supplement a wild population.

Summary

The protection of fitness in stocks of Pacific salmonids supplemented with hatchery fish requires measures to maintain genetic differences between stocks and adaptations within stocks. Differences between stocks can be maintained by ensuring that crossbreeding of stocks does not occur. Local adaptations in supplemented stocks are put at least risk when supplementation hatchery fish are the offspring of wild parents. If higher levels of risk are acceptable for management purposes, the use of hatchery fish that have been protected from the effects of small population size and artificial selection is recommended.

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Exploitation of Noncommercial Food Resources of the Antarctic Ocean by Salmon Ranching

by

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Abstract. Salmon ranching has become a new type of ecological industry. At present, North Pacific countries release over 5 million artificially reared juveniles to the ocean; however, the forage capacity of the region may restrict further artificial breeding of salmon. New areas must be sought to ensure the profitability of the industry.

The Antarctic Ocean, especially subantarctic waters, possesses tremendous underutilized resources of macroplankton, which is excellent food for salmon. The stock of krill is estimated to be 200–300 billion metric tons. The idea to utilize the excess food resources of the Antarctic waters by salmon was proposed by Joiner, Mahnken, and Clark (1974) in their paper "Salmon—Future Harvest From the Antarctic Ocean." This concept was based on scientific results obtained at our research institute, All Union Research Institute of Marine Fisheries and Oceanography, the leading Russia scientific institute for fisheries exploration of the Antarctic. They wrote: "Since we cannot yet harvest krill economically by ourselves ought we not to try to get help from some other creature better equipped by nature to do it." However, this idea has not been implemented yet.

The most promising regions for salmon ranching are the southernmost waters of Chile and Argentina. At present salmon are raised at sea in cages (salmon farming) in this region. However, salmon ranching, that is, releasing very small salmon to grow in the open sea, may be a more profitable method. The efficiency of salmon ranching is 3–5 times higher that of salmon farming, and it can make this area an important supplier of salmon to the world market.

We have prepared several new proposals for projects that could be initiated with different countries within the framework of the exploration of food resources of the Antarctic Ocean. Sockeye salmon (*Oncorhynchus nerka*) is one of the most profitable species of salmon, for which there is a good market in Japan and other Asian countries. The sockeye salmon is the most coldwater-loving and, in terms of feeding habits, the most planktonic species of salmon, which makes it the best species for Antarctic waters. Our recent data show that sockeye salmon weighing about 2 g may become a smolt and can be released to the ocean. Then it will take 5 to 6 months instead of 2 years to obtain a full-size smolt. Thus, we would expect a very good economic effect from ranching with sockeye salmon, exceeding that for Japanese chum salmon (*Oncorhynchus keta*) by 2–4 times. We have a convenient method to assess the smoltification process and to determine the optimum timing for releasing smolts that would provide the best commercial return.

The most promising and economically profitable culture operation is the combination of farming and ranching: Some part of the juveniles are released to the ocean for ranching, and the rest are reared in sea cages. Feeding of caged fish can be made considerably cheaper by using krill taken by the U.S.S.R. fishing fleet in the adjacent areas.

Combined salmon culture operations can most conveniently be placed off southern Chile and in the Strait of Magellan, where there are protected bights, good water exchange, and adequate thermal regime. Annual variations in temperature are low, 6 to 9°C (average 8°C), which is considered to be optimum for sockeye salmon.

Technological and scientific aspects of our proposals may become a basis for cooperation in the utilization of food resources of the Antarctic Ocean using salmon. Soviet vessels take krill in the Antarctic and are interested in such a program as a potential supplier of food for salmon farms and buyer of cultivated salmon.

Salmon culture is proceeding at a great pace in the Southern Hemisphere. Long-term Japanese experience on chum salmon ranching shows that it is possible to harvest the oceanic ecosystem and to receive the benefits from nature without destroying it.

The idea to utilize salmon for harvesting planktonic resources of the Antarctic Ocean emerged 15 years ago; the time has come to act on the idea.

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Unusual Culture Practices for Pacific Salmon in Alaska

by

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Abstract. Enhancement has become a major component of the management of salmon fisheries in Alaska during the past 10–15 years. At present, over 100 enhancement-type projects exist, and most involve the freshwater or marine culture of salmon. Most Alaska salmon hatcheries are located in coastal tidewater areas rather than inland on major rivers, like hatcheries in other regions. Strategic siting of enhancement facilities away from the vicinity of large natural production systems minimizes conflicts between hatchery and wild stocks. Unusual fish culture practices used in Alaska include use of high-density substrate incubators capable of producing large numbers of high-quality fry in minimal space, extensive use of marine net-pens in protected estuaries for production and imprinting of fry or smolts, development of floating raceways for freshwater and estuarine rearing, and use of lakes inaccessible to anadromous adults as natural rearing areas for smolt production. Alaska has developed strict laws and regulations concerning fish diseases and salmon stock genetics, including prohibiting the transport of fish and eggs between regions of the state, managing mixed-stock fisheries to favor wild stocks over hatchery stocks, and developing wild stock sanctuaries.

Five species of Pacific salmon (*Oncorhynchus* spp.) occur in Alaska, along 4,000 km of coastline—from southeastern Alaska (latitude 55°N) to the North Slope drainages that flow into the Beaufort Sea (latitude 72°N). The area contains thousands of salmon runs in waterways ranging from short coastal streams to large continental river systems and is divided into many separate management districts (Fig. 1).

The commercial harvest of Alaska salmon is over 100 years old and has been characterized by many dramatic changes. Annual harvests have fluctuated from 30 to 152 million salmon due to varied run strength and other factors. Harvesting methods and fishery policies have played important roles in the evolving Alaska salmon scene.

Hatchery and enhancement technology developed during two distinct periods. The first period (late 1800's to 1930's) focused on sockeye salmon (*O. nerka*) although some culture of other salmon and trout did occur. The early hatcheries, about 20 total, were located in southeastern Alaska, Prince William Sound, and on Kodiak and Afognak Islands (Roppel 1982). While some hatcheries annually produced millions of eggs, many did not produce adult salmon returns sufficient to maintain brood stocks or contribute to established fisheries. Many hatcheries failed due to a limited understanding of basic biology and sound hatchery technology, such as suitable diets and disease management. Although some individual hatcheries were successful, all early hatcheries eventually closed due to poor overall performance. Complex political issues were also involved in these closures.

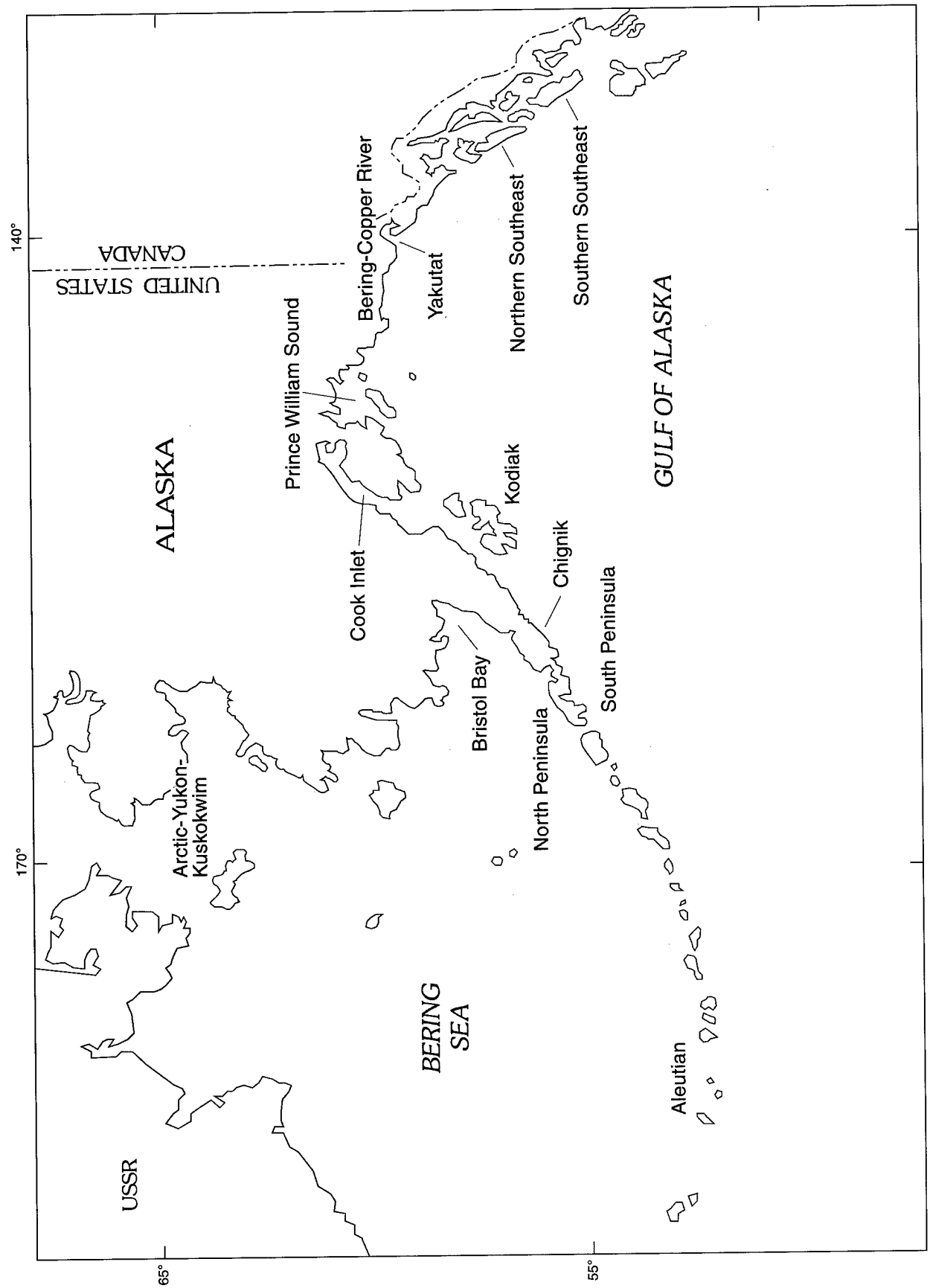

Figure 1. Location of some Alaska salmon fishery districts.

The second period of salmon hatchery activity in Alaska began in 1971, when the state legislature created the Division of Fisheries Rehabilitation, Enhancement, and Development (FRED) within the Alaska Department of Fish and Game (ADF&G). Two important factors were precursors to the FRED Division: Salmon runs in Alaska had reached all-time-low abundance levels in the late 1960's and early 1970's, and salmon hatchery programs in other geographic areas (especially in Washington State and Japan) were using biological knowledge and improved technology to make major contributions to fisheries.

In addition to the formation of FRED, other events accelerated the development of enhancement projects in Alaska. In 1974, legislation was passed to allow private nonprofit (PNP) groups to operate hatcheries for common property fisheries—"a concept unique to Alaska"—and, in 1976, the formation of regional aquaculture associations was authorized under the PNP laws.

By the end of 1988 there were many new enhancement-type projects in Alaska. Forty-eight of the projects were production or research hatcheries: 16 operated by FRED, 29 by the PNP and regional aquaculture association programs (Holland 1989), two Federal Government research hatcheries, and one production facility operated by a Native American tribal group. Thirty-six were scientific-educational aquaculture projects, many operated in conjunction with school districts.

Unlike earlier efforts, most contemporary salmon hatcheries are making significant contributions to fisheries. During 1987, for example, over 1.3 billion eggs were collected by Alaska hatcheries, and an estimated 28% of the total commercial salmon harvest was derived from hatcheries (Holland 1988). In 1988, the total harvest of salmon in Alaska exceeded 100 million fish (Savikko 1989); an estimated 25 million Alaska hatchery salmon were either caught in regulated fisheries or returned to their release sites. The 1988 contribution from hatcheries represented about 80% of the sockeye salmon and 90% of the pink salmon (*O. gorbuscha*) caught in lower Cook Inlet and 90% of the pink salmon caught in Prince William Sound (Holland 1989).

Different and often unusual fish culture practices and strategies have evolved during the rapid expansion of salmon enhancement activities. Some new practices resulted from a general awareness of strengths and weaknesses of similar programs elsewhere. Others grew out of the distinctive geographic and geologic features at different Alaska sites. This report reviews some of these salmon culture practices concerning (1) the location of hatcheries; (2) technological innovations, including high-density substrate incubators, marine net-pens, and development of floating raceways; and (3) the use of lakes inaccessible to anadromous adults for natural rearing areas. The phrase "unusual culture practice" as used in this report does not imply uniqueness to Alaska, only that the practice may have been developed to a greater extent here than elsewhere.

Location of Hatcheries

Most salmon hatcheries in Alaska are in the southwestern and south-central portions of the state (Fig. 2) in coastal areas at or near tidewater. Salmon hatcheries outside Alaska are often located inland on major river systems, whereas many in Alaska are sited on small coastal water sources removed from major salmon-producing areas, so the impact of hatchery stocks on wild stocks is minimal. Minimizing interactions between hatchery and wild stocks involves two important considerations: harvest management strategies and biological concerns.

Some Alaska hatcheries focus production on "net species" of salmon—those salmon commercially harvested primarily by gill nets or purse seines (sockeye, pink, and chum). A harvest management strategy is to site these hatcheries where their stocks can be caught after migration patterns sort them from adjacent wild stocks of fish.

Because much of Alaska's wild salmon producing areas are still reasonably pristine, careful attention is given to maximizing wild stock production by maintaining optimum spawning populations. In mixed-stock fisheries involving large-scale enhancement projects, weak run components are often wild stocks. Therefore, careful selection of hatchery sites is very important. Good hatchery sites have reasonably large harvest management areas, where returning hatchery fish can be caught in common property fisheries while the fish are still silver bright and of high market value.

Biological characteristics of hatchery and adjacent wild spawning stocks need to be considered when selecting hatchery sites. To reduce interacting between hatchery and wild fish, many hatcheries are located in watersheds and on water sources that do not

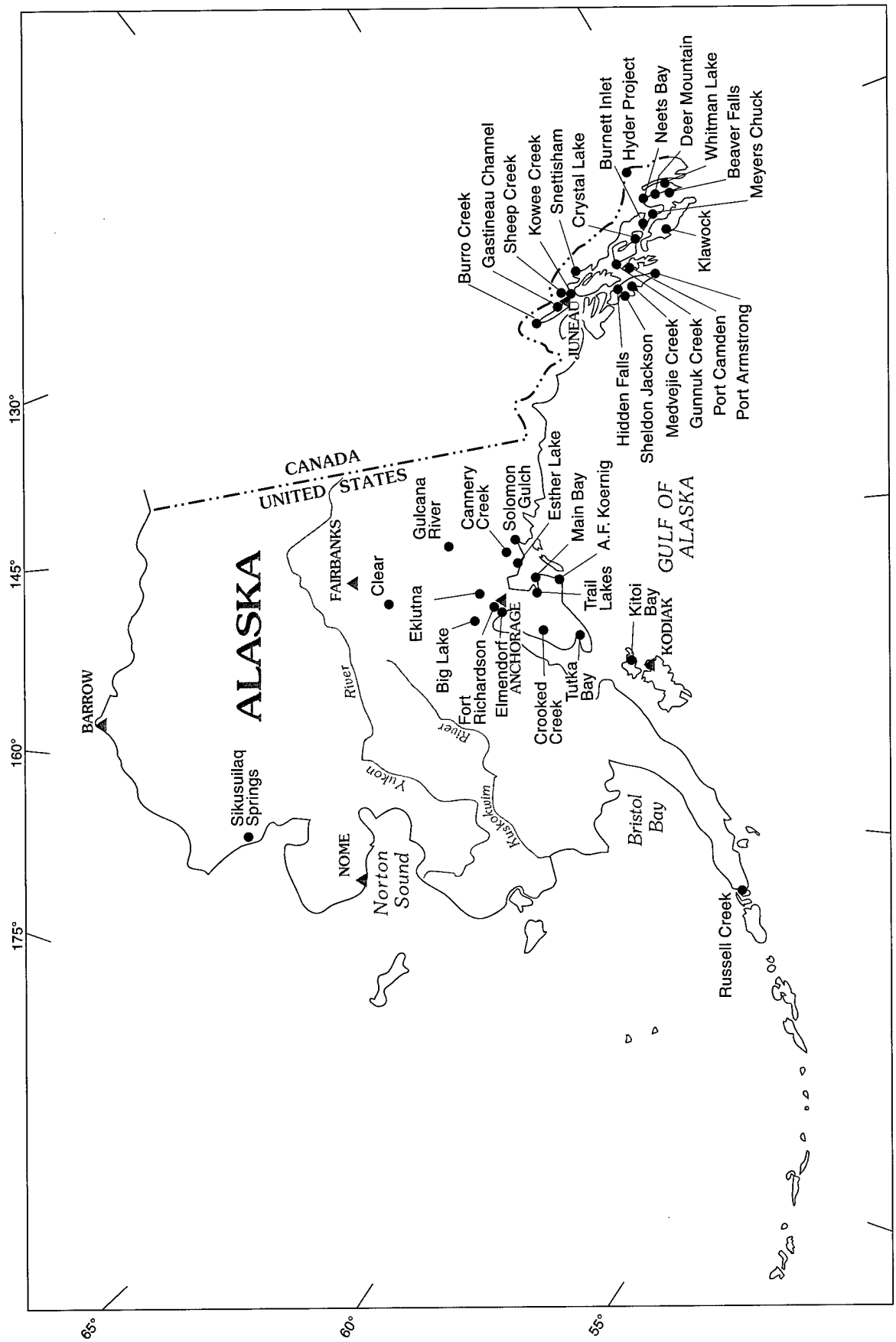

Figure 2. Location of most Alaska salmon hatcheries (from Alaska Department of Fish and Game, 1989).

have endemic anadromous salmon runs. Such water sources are common in southeastern and other rugged coastal portions of Alaska because of post-glacial uplift and the presence of barrier falls on streams. The many narrow channels, fjords, separate bays, and inlets along the Alaska coast provide opportunities for developing hatchery runs of salmon reasonably discrete from adjacent wild runs.

Stock origins and the mix of species also have been considered during contemporary hatchery management. Hatchery stocks are usually derived from wild stocks within the same vicinity, based partially on the assumption that these stocks are better adapted for local freshwater and marine environments. Alaska adheres to a live fish transport policy that prohibits movement of stocks between different regions of the state. Biological features such as run timing, other migration characteristics, and disease histories are considered in selecting stocks for use at specific hatcheries. Although hatchery stocks may be derived originally from local sources, they are likely to become genetically differentiated after several generations in a hatchery environment (Ryman and Stahl 1980). Siting and management of Alaska salmon hatchery runs are therefore structured to prevent detrimental genetic effects that might occur from hatchery fish straying and interbreeding with wild fish (Alaska Department of Fish and Game 1985).

To further minimize possible long-term impacts of hatchery fish on wild stocks, genetic sanctuaries are being considered for salmon populations. Such sanctuaries would exclude enhancement activity at designated locations; however, commercial or recreational fisheries would be allowed. These areas could be used for gamete extraction for use in nonsantuary locations.

Policy development on siting, management, and integration of hatchery and wild stock production is done on a regional basis coordinated by ADF&G. There are seven regional aquaculture associations in Alaska. These associations are responsible for development of long-range comprehensive and short-range strategic plans; Regional Planning Teams determine the location, mix of species, and production levels of each species allowed at each hatchery.

High-density Substrate Incubators

Although natural salmonid incubation occurs in a dark, gravel environment, many early North American hatcheries utilize smooth tray, trough, or basket incubation systems in relatively bright light. In contrast, the successful Japanese chum salmon hatchery program developed a seminatural incubation system, where alevins developed in a dark shallow, gravel-lined raceway or pond (Mathews and Senn 1975; Moberly and Lium 1977; Kobayashi 1980). Experimental hatchery work with chum salmon in the Soviet Union also indicated that incubation should be in gravel (Kolgaev 1963; Levanidov 1966).

Contemporary hatcheries in Alaska have production capacities in excess of 100 million fry and use a variety of high-density substrate incubation systems. Many scientists, including Marr (1963), Brannon (1965), and Bams (1969), have found that alevins incubated under darkness in gravel or on rugose substrates converted yolk more efficiently, had more stamina, and better avoided predators at emergence than alevins incubated under light on smooth surfaces. This knowledge accelerated North American development and production of improved salmon incubators, including various types of gravel boxes (Bams 1970, 1972, 1974; Bailey and Taylor 1974a; Bailey et al. 1976, 1980), gravel trays (Blackett 1974), and gravel ponds (Senn et al. 1973).

Researchers also began experimenting with plastic materials for use as substrates in salmon incubators. The initial focus of plastic substrates in production hatcheries was in Alaska, where by 1980 an estimated 90% of all hatchery salmon were incubated on these artificial substrates (Heard 1981). Plastics provided the advantages of lighter weight, greater ease of handling, and, perhaps, greater egg and alevin seeding densities. Some plastics used as substrates for incubation included turf-like sheet material (Bailey and Taylor 1974b) and different shapes of individual plastic particles (Leon 1975; Snyder 1979). Researchers showed that plastics could be successfully substituted for gravel, even though there were some behavioral differences in alevins and fry during incubation and emergence (Leon 1982; Taylor 1984; Bailey et al. 1984).

Most observed differences in alevin and fry behavior between plastic and gravel substrates can be explained by two variables: egg seeding density and void spaces in the incubation environment. Seasonal timing and rate of fry emergence vary with size and type of substrate material. Leon (1982) and Taylor (1984) attributed accelerated emergence in different types of plastic substrates to ease of movement of

alevins and fry within and during egress from the substrate. Bams (1979) found that fry in gravel emerge earlier and at higher rates as gravel sizes increase with concomitant increases in interstitial spaces. In general, plastic substrates have much higher porosities (void spaces) than gravel. Heard (1981) found that four types of plastic materials used as substrates had porosities ranging from 87% to 95%, while stream gravel with particle sizes that varied between 12 and 30 mm had porosity of only 46%.

The use of plastics for substrates in salmon incubation led to development of many different kinds of incubators in Alaska, including three that were awarded U.S. patents: the Auke Bay Incubator (Salter 1975), the Kitoi Incubator (Blackett 1985) and the Zenger Incubator. Two incubator styles evolved (Kaill 1985); the deep matrix box-type and the shallow matrix stacked tray-type. Both use upwelling waterflow through substrate (either gravel or plastic); box-type incubators have single-pass waterflow, while stacked tray-types have water reuse and aeration features.

At present in Alaska facilities, most salmon egg incubation occurs in either Zenger incubators (a stacked tray-type) or "R"-series incubators (a cylindrical version of the deep matrix box-type). Although some facilities still use gravel (Roberson and Holder 1987), most—especially those producing large numbers of pink, chum, or sockeye—use plastic-partial substrates either in saddle (Leon 1975, 1982) or ring shapes (Snyder 1979; Taylor 1984).

A few Alaska facilities, notably some that raise coho (*O. kisutch*) or chinook (*O. tshawytscha*) salmon in stacked trays, do not use substrate materials during incubation. When incubated on smoother surfaces, coho and chinook salmon apparently are less susceptible than other species to a common incubation malady, yolk-sac malformation (Emadi 1973). Also, because both of these species are routinely cultured for extended periods before release at the smolt stage, there may be increased opportunities for overcoming deficiencies in the quality of fry incubated on smooth surfaces without substrate.

Marine Net-Pens

Floating marine net-pens play a major role in Alaska salmon enhancement. Most hatcheries are located in temperate coastal areas near tidewater and in protected waters, where they can utilize marine net-pens year round. Net-pens are dependant on tidal currents for water exchanges and provide relatively large rearing volumes at low cost. Use of marine net-pens, as discussed by Martin and Wertheimer (1987), can increase the efficient use of available freshwater at a hatchery.

Alaska net-pen culture of Pacific salmon is used mostly in short (1 to 2 months) and intermediate (3 to 8 months) rearing programs before juveniles are released for anadromous adult returns. Marine net-pens in Alaska also are being used at tidewater hatcheries for holding returning adult salmon while they ripen and mature before spawning (Wertheimer and Martin 1980; Wertheimer 1981, 1984).

The most extensive use of net-pens in Alaska involves short-term rearing of pink and chum salmon fry. For example, I estimate that in 1987 over 600 million pink and chum salmon fry were short-term reared in marine net-pens at 23 facilities, representing over 75% of the state's total hatchery production of these species. Although applications vary considerably between facilities, a typical program involves a 30- to 60-day rearing period with fry, which more than doubles their initial weight before release. Unlike fry in Far East hatcheries, Alaska pink or chum salmon hatchery fry are not usually fed in freshwater. Feeding generally starts in an estuarine net-pen. Short-term rearing of pink and chum salmon fry in Alaska typically produces higher fry-to-adult marine survival values than those of unfed fry released at emergence (Martin et al. 1981; Thrower et al., in press; Taylor and Landingham, in press).

Intermediate-term rearing in marine net-pens is also used in Alaska for coho, chinook, and sockeye salmon smolts. I estimate that in 1987 about one-third of the 25 million coho and chinook salmon smolts produced in Alaska hatcheries involved some marine net-pen culture (Holland 1988). After differing intervals of freshwater rearing, there are two primary strategies generally used for net-pen culture of these species (Martin and Wertheimer 1987). The first strategy involves late summer or fall entry into net-pens after most presmolt growth is completed in freshwater, followed by overwinter culture in marine net-pens, and ending with yearling smolt releases in mid to late spring. Variations of this strategy have been used for smolt releases of coho (Heard and Crone 1976; Martin and Wertheimer 1987), sockeye (Wertheimer et al. 1983), and chinook salmon (Heard et al, 1979). The

second strategy differs in that all rearing during the first year of life occurs in freshwater. Other than involving older life stages of different species, the strategy is similar to that used for pink and chum salmon fry. In this procedure, net-pen rearing begins in early to mid spring and usually lasts for 30 to 60 days before smolts are released. Martin and Wertheimer (1987) reviewed an Alaska usage of this strategy with coho salmon where marine survival from a spring net-pen group of smolts was similar to that of two other smolt groups, one cultured only in freshwater and the other cultured overwinter in net-pens before a spring release.

Marine net-pens for short-term rearing of smolts during spring may have greatest potential use for off-site releases away from the immediate hatchery vicinity, which is a new practice growing in use in Alaska. In these cases, net-pens also become new environmental "holding" areas for imprinting of smolts before intended release. Two reasons for off-site releases of juvenile salmon include limited estuarine rearing capacity in the immediate hatchery vicinity and the desire to relocate the adult harvest away from the hatchery. Selecting areas for off-site releases dictates careful consideration of many of the same issues required for siting hatcheries—especially those relating to the interactions of wild and hatchery stocks. Two highly successful off-site release programs are located in south-central Alaska. Both have resulted in a new recreational fishery harvest of returning chinook adults to the off-site area (Dudiak et al. 1987; Dudiak 1988).

Culturing young salmon in marine net-pens requires consideration of many factors to ensure healthy fish and readiness for survival in the net-pens: size and condition of fry or smolts, precise seasonal timing of net-pen entry, stock differences in each species, salinity and temperature of the net-pen environment, presence or absence of a low salinity surface lens and other freshwater parameters, and other site-specific features.

Marine net-pens used in Alaska vary greatly in size and shape. A popular rectangle design is 12.5 m long by 12.5 m wide by 6–7 m deep (about 1,000 m^3) in rearing volume). Netting is usually of nylon or polyester material with 3–4-mm square-mesh openings for pink or chum salmon fry and 6–10-mm openings for coho, chinook, or sockeye salmon smolts.

Floating Raceways

The development of floating raceways initially grew out of a need for salmon rearing containers in areas with limited suitable shore space. Raceways designed to function while suspended in water were first tested in 1973 in southeastern Alaska for use in conjunction with estuarine net-pens. Five types of raceways were tested, including configurations that used either horizontal or vertical waterflows. An inverted frustum-shaped design, using vertical waterflow, was selected for a standard rearing unit (Heard and Martin 1979). Advantages of the floating vertical raceway include low construction cost and high water quality for the rearing environment. Unlike net-pens, which depend on tidal flushing for water exchanges, floating raceways are similar to land-based raceways in that they are closed systems, dependent on a controlled waterflow for exchanges in the rearing environment.

Floating vertical raceways consist of three components: an impervious plastic liner, a screened outlet drain, and a flotation collar that provides a walkway and support railing. Waterflow enters the raceway at the surface and spirals down to exit through the bottom outlet drain. A slight hydraulic head (3–6 cm) inside the raceway maintains a turgid shape to the liner. Many modifications and improvements to the original design, including the use of several sizes, have been made after more than a decade of use (Martin and Heard 1987).

Floating vertical raceways can be effective containers for rearing juvenile salmon for production and research purposes. For example, at the Little Port Walter station in southeastern Alaska, 8 to 12 raceways, with a 22.7 m^3 rearing volume each, have an annual production of 10,000–20,000 experimental smolts each. A smaller version with <1.0m^3 rearing volume is used to raise juveniles from individual matings (Heintz and Joyce 1992). At the Neets Bay Hatchery, operated by the Southern Southeastern Regional Aquaculture Association, larger vertical raceways with 70.8 m^3 rearing volume are used to raise production lots of smolts. Floating vertical raceways also have been used for culturing juvenile salmon at precise intermediate salinities (Heard and Salter 1978) and for holding adult salmon during maturation in freshwater and seawater (Wertheimer 1984).

Barriered Lakes for Rearing

Much of the coastline in southern Alaska is characterized by mountainous regions with sharp relief. Numerous lakes formed as glacial ice receded beginning about 9,000 years ago (Wahrhaftig 1965). Many of these lakes lack fish due to timing of postglacial fish dispersal and formation of barrier falls on outlet streams. At early and intermediate recessional stages, anadromous fish populations became established in some lakes, only to become blocked later as new barriers developed from continued postglacial uplift. Lakes without migration barriers usually have anadromous runs of salmon, and some naturally fishless lakes now have self-sustaining fish populations—especially of trout and char—from plantings by man.

Lakes inaccessible to adult salmon migrating upstream may provide locations for the natural rearing of juveniles and production of smolts from plants of hatchery fry. In such cases, if the barrier falls are not destructive to seaward migrant smolts, adult salmon returns to the outlet stream or to the lake vicinity can be produced. Self-sustaining anadromous runs do not result from this enhancement method; therefore, all returning adult salmon are available for harvest or other uses, including the production of hatchery gametes to recycle the process.

Research on smolt production in lakes with barriers in Alaska began with the planting of 12,000 coho salmon fry in 1.4-ha fishless Tranquil Lake on Baranof Island in 1969. The study produced over 7,000 age 1 or age 2 emigrant smolts, and over 700 adult salmon returned to the outlet stream. Subsequent fry plants in Tranquil Lake and in two other nearby lakes established that this enhancement method works for coho salmon (Crone 1981). Stocking two lakes in the same vicinity and using a similar experimental design, Hard (1986) demonstrated the principle also is suitable for producing chinook salmon smolts, although yield was somewhat less than for coho.

Many physical and biological variables must be considered for successful stocking of fry in fishless and barriered lakes for smolt and adult salmon production. Important physical factors include size, depth, shoreline configuration, and elevation of the lake; general features of the watershed and water quality, including nutrient structure; and various aspects of the barrier falls. Biological factors include the presence or absence on population dynamics of other fishes, population structure and characteristics of zooplankton and other invertebrate prey, species and numbers of fry planted, and seasonal issues relative to timing and size of fry planted and to zooplankton blooms. The socio-biological issues of returning adult salmon are also of concern: When, where, and how will adults be harvested? And by whom? Will unharvested adults produced from lakes with barriers stray and impact wild stocks in the areas?

At present, integrating the above and other issues, the Northern Southeastern Regional Association manages a 10-year old, production-scale, fry stocking project in lakes with barriers. The project, involving periodic plants of coho salmon fry in 8–10 large oligotrophic lakes on Baranof and Chichagof Islands, has contributed to the harvest from troll fisheries in southeastern Alaska. Issues arising from this project include the need for periodic nutrient enrichment of the lake habitat and the detrimental effects of cestode parasitism on juvenile salmon rearing in lakes. Parasitism on juvenile salmon by immature cestodes in lakes with barriers is linked to the utilization of calanoid copepods as food by the young salmon. Heintz et al. (in press) showed that, under certain conditions, heavy cestode parasitism can reduce survival to smolt stage of chinook and coho salmon fry planted in lakes with barriers by as much as 41%.

While the coho and chinook salmon studies in lakes with barriers were being conducted in southeastern Alaska, studies with sockeye salmon were taking place in south-central Alaska. Because juvenile sockeye salmon rear naturally in large oligotrophic lakes more often than chinook or coho, sockeye are probably the most efficient species for these lake plants in terms of total biomass yield of smolts. Studies at Leisure Lake in the Kachemak Bay area of Cook Inlet demonstrated the success of this principle with sockeye salmon (Bechtol and Dudiak 1988). In 1976, 59,800 sockeye salmon fry were stocked in the 105-ha lake. Although Leisure Lake did have other fishes, the initial sockeye fry plant resulted in an estimated 33,200 age 1 or age 2 emigrant smolts and over 1,500 returning adults (Bechtol and Dudiak 1988) Additional experimental sockeye fry plants in Leisure Lake at increasing densities, some with nutrient enrichment, have led to an increased understanding of the complex dynamics of smolt production in Alaskan lakes (Koenings and Burkett 1987).

Summary

Enhancement of Alaska salmon during the last 10–15 years has undergone an active period of development, including the construction of major production hatcheries along the southeastern, south-central, and southwestern coastlines. At present, these hatcheries are making significant contributions to the annual salmon harvest, which historically is at its highest level. Principal hatcheries are operated by the FRED division of ADF&G and by Regional Aquaculture Associations so that hatchery and wild stock interactions are minimized. Hatchery sites are selected carefully. Most hatcheries are located on water sources that do not have endemic runs of salmon; many are located where some discrete harvesting of stocked fish occurs. In addition to siting of facilities, consideration is also given to the species, stock origin, and production levels at each hatchery to further minimize impacts on wild stocks.

Fish culture practices have evolved that adapt modern fish culture techniques to the unique physical features of Alaska. High-density substrate incubators, marine net-pens, floating raceways, and lakes with barriers to migration are used for rearing salmon. These and other technological innovations at individual hatcheries are contributing to the success of contemporary salmon enhancement efforts in Alaska.

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Methods for Assessing the Effects of Rearing Conditions on the Health and Physiological Quality of Anadromous Salmonids

by

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Abstract. The stress of unfavorable hatchery rearing conditions and fish-cultural practices such as handling, trucking, or disease treatments can seriously affect the health and physiological quality of juvenile anadromous salmonids. In particular, adverse rearing conditions can interfere with the normal development of the parr-smolt transformation, resulting in insidious physiological and behavioral effects, such as impaired migratory behavior and reduced seawater tolerance, that may not be apparent until after release. Physiological tests and performance challenge procedures are not available that can be used to identify such problems as they develop during rearing. Recommendations are given for the tests and procedures judged most promising in identifying the fish-cultural practices and environmental conditions that will minimize stress and improve the health, quality, and early marine survival of juvenile anadromous salmonids released from rearing facilities.

Studies to improve the health, quality, and survival of anadromous salmonids released from federal mitigation hatcheries are an important part of the fishery research program of the U.S. Fish and Wildlife Service. Important advances have been made, and prerelease health and physiological quality are now known to affect the travel time and eventual seawater survival of migrating smolts (Beeman et al. 1994). However, many of the required physiological methods are still at a relatively early stage of development, and the biological data base needed to assess the point at which the stress of rearing conditions will begin to exceed acclimation tolerance limits and debilitate health and quality is still incomplete. Thus, by necessity, factors such as hatchery growth and mortality rates, physical condition factor, and delayed population effects (e.g., reduced ocean survival and adult returns) often still must be used as indicators that stress during rearing exceeded physiological tolerance limits (Wedemeyer et al. 1990). Such information has proven to be difficult to use in establishing the required cause and effect relationship (Vaughn et al. 1984; Cone 1989). An interagency research program is under way to provide the physiological information needed to identify rearing conditions that will prevent fish health and quality problems and lead to optimum seawater growth and survival (Schreck 1981; Wedemeyer et al. 1990).

Blood Chemistry

A variety of blood chemistry tests can now be recommended for use in assessing the stress of rearing conditions and fish-cultural practices on fish health and physiological quality (Sandnes and Waagbo 1988). Few of these require complex equipment or facilities. Some, such as impression smears of skin mucus to detect acute stress, require only simple prepackaged reagents (Wechsler 1984), and others are readily automated (Smith and Ramos 1980). Blood chemistry tests are also useful in studies of the pathogenesis of infectious diseases (Barham et al. 1980), in providing information on the biological effects of sublethal contaminant exposure, and in fish nutrition studies required for diet development (Wedemeyer and McLeay 1981).

Much of the current information on the physiological tolerance limits to the stress of rearing conditions has been provided by means of blood chemistry tests. Procedures include measurements of circulating levels of catecholamine and corticosteroid hormones (Mazeaud and Mazeaud 1981; Donaldson et al. 1984; Sumpter et al. 1986) or the secondary blood chemistry changes that occur as a result of stress hormone activity, such as hyperlacticemia, hyperglycemia, or diuretic hypochloremia (Eddy 1981).

Corticosteroid and catecholamine hormone determinations provide the most direct estimate of the severity and duration of stress and of the time fish need for recovery (Barton and Peter 1982; Barton et al. 1985). However, the analytical procedures required are complex and require specialized research facilities (Sumpter and Donaldson 1986). Thus, the secondary blood chemistry changes such as hyperglycemia, which are the result of stress hormone action, are often measured instead (Silbergeld 1975). In addition, measuring the extent and duration of secondary effects such as hyperglycemia integrates those aspects of the stress response mediated through direct sympathetic nervous system and humoral pathways (Passino 1984).

Plasma glucose can be measured quickly, accurately, and precisely with only 5-10 mL of sample by either manual or automated methods. The small amount of blood required permits evaluating the severity of stress in fish weighing only a few grams, as well as the repetitive blood sampling of larger individual fish. In addition, the technical procedures and equipment required for blood glucose determinations are simple enough that studies under field conditions are practical. To minimize variability, factors such as diet composition, time since last feeding, developmental stage, and season of the year should be standardized because these affect liver glycogen stores and thus the magnitude of the hyperglycemic response.

Blood-sugar determinations can also be used in conjunction with stressor challenge tests to assess physiological quality in terms of ability to mount a stress response and achieve compensation within a given period. For example, a procedure has been standardized for evaluating tolerance to water quality alterations using the extent of hyperglycemia as the indicator of a sublethal biological effect.

Blood-sugar determinations can also be used to evaluate tolerance to single or multiple stressors, such as handling or handling accompanied by either hypoxia, temperature, or water chemistry alterations, and to determine the time fish need for recovery (Barton et al. 1986). Performance tests using the hyperglycemic response to select genetic strains physiologically best able to compensate for hatchery conditions or proposed fish-cultural practices are also feasible. These tests should include not only measurements of the severity and duration of hyperglycemia, but also its variability (F-test of variance ratios) and recovery rate (return of elevated plasma glucose to baseline values) after the challenge is removed.

Hematology

Hematological determinations have long been used to provide diagnostic information about fish health and physiological quality (Houston and Koss 1984; Peters and Schwarzer 1985). Changes in the erythrocyte count (as approximated by the hematocrit) or in hemoglobin values following acute stress are useful as presumptive (indirect) indicators that hemodilution or hemoconcentration have occurred (Milligan and Wood 1982). However, because anemia, polycythemia, or erythrocyte swelling may also occur (Soivio and Nikimaa 1981), the plasma water concentration should always be determined as confirmation. Changes in the normal blood clotting time and in the differential leukocyte count are also sensitive indicators that environmental stress is beginning to adversely affect fish health. Eosinophilia may occur under certain conditions, but little research has been

conducted on its sensitivity, variability, or usefulness in monitoring health in anadromous fishes.

In general, a moderate to severe lymphocytopenia will occur when stress from rearing conditions becomes severe enough to affect fish health (Pickering 1984). Specifically, stress, perhaps through the mediation of ACTH and corticosteroids, results in lymphocytopenia, monocytopenia, and neutrophilia. The mechanism of this effect in fishes is poorly understood (Pickering and Pottinger 1985); nevertheless, the practical result is suppression of the immune response and increased susceptibility to infectious fish diseases (Ellis 1981).

The most accurate and precise determination of leukopenia is the classical differential blood cell count. However, for some purposes the rapid, approximate leukocrit measurement will suffice (Wedemeyer et al. 1983). The calculation is the same as that of the familiar hematocrit, except that the volume of the leukocytes in a hematocrit tube is expressed as a percentage of the total blood volume instead of the volume of the erythrocytes. As in blood glucose determinations, the leukocrit can be measured in fish as small as 1 g. However, young salmonids have inherently low leukocrits, and the use of fish 2 g or larger is recommended (McLeay and Gordon 1977). This size also allows somewhat larger blood samples to be taken, which eliminates the need for pooled samples when leukocrit and other blood chemistry determinations are required.

For salmonids and other fishes in which lymphocytes make up the majority of the circulating leukocytes, the leukocrit can be used as a simple, rapid test for determining the point at which unfavorable environmental conditions or other stress factors result in a depressed white cell count in the affected fish (McLeay 1975). In interpreting leukocrit data, remember that the significance of this measure of the secondary stress response may differ from that of other tests. For example, although hyperglycemia can be elicited as a secondary response to catecholamine and glucocorticosteriod stress hormones, leukopenia does not seem to be associated with catecholamine production. Thus, the leukocrit and plasma glucose values, which can be measured from the same centrifuged blood sample, provide physiological information on two effects on fish health for each rearing condition evaluated.

Tissue Chemistry

Tissue chemistry changes that can be used to indicate that adverse effects on fish health and physiological quality have occurred include reductions in muscle or liver adenylate energy charge, muscle and liver glycogen, and interrenal Vitamin C depletion (Morata et al. 1982; Vetter and Hodson 1982; Reinert and Hohreiter 1984). Histological effects include atrophy of the gastric mucosa (Peters et al. 1980) and interrenal hypertrophy (Brown et al. 1984).

To assess interrenal hypertrophy, mean nuclear diameter, mean interrenal cell area, or nuclear:cytoplasm ratios are measured in stained sections of anterior kidney tissue (Scott and Rennie 1980; Pickering and Stewart 1984). To assess changes in the gastric mucosa, decreased mucous cell diameter is used as an index (Peters et al. 1980). Subordinate animals in the social hierarchies that develop prove to be under measurable stress within 5–10 days.

The duration of adverse rearing conditions has an important bearing on the severity of the tissue changes that develop. Acute stress results in a reversible depletion of liver glycogen, interrenal Vitamin C, and liver or muscle adenylate energy charge. The rearing conditions under which chronic stress will result in interrenal hypertrophy in salmonid fishes are not clear (Pickering and Stewart 1984). However, if the stress factor is removed or acclimation is achieved, interrenal function, liver glycogen stores, and adenylate energy charge may gradually be recovered.

Physiological tests that can be recommended to identify effects on fish health and quality are summarized in Table 1. Estimated normal values partially compiled from Hille (1982) are given in Table 2.

Whole-Animal Responses

Experience gained from studies of the physiology of fish has shown that several whole-animal responses can be used to monitor the effects of rearing conditions on fish health and physiological quality (Schreck 1981), including: (1) changes in the normal rate of metabolic processes such as oxygen consumption; (2) effects on osmoregulation and biogenergetic parameters; (3) behavioral changes such as feeding, migratory, or predator avoidance; and (4) changes in physical condition, food conversion, growth, and survival. Decreased survival during rearing is frequently

Table 1. Physiological tests and interpretive guidelines recommended to evaluate effects of environmental stress on fish health.

[Controls are usually needed for comparison because normal range estimates are often unavailable. Sample size is normally at least 10 fish per group, depending on the coefficient of variation of the test employed]

Physiological test	Diagnostic significance if results are	
	Low	High
Adenylate energy charge (muscle, liver)	Energy drains due to chronic stress	Normal bioenergetic conditions
Blood cell counts		
Erythrocytes	Anemias, hemodilution, impaired osmoregulation	Stress polycythemia
Leukocytes	Leukopenia due to acute stress	Leukocytosis due to bacterial infection
Thrombocytes	Abnormal blood clotting time	Thrombocytosis due to acute or chronic stress
Chloride (plasma)	Gill chloride cell damage, compromised osmoregulation	Hemoconcentration, compromised osmoregulation
Cholesterol (plasma)	Impaired lipid metabolism	Chronic stress, dietary lipidemia
Clotting time (blood)	Acute stress	No recognized significance
Cortisol (plasma)	No recognized significance	Acute or chronic stress
Gastric atrophy	No recognized significance	Chronic stress
Glucose (plasma)	Inanition	Acute or chronic stress
Glycine incorporation (scales)	Reduced growth	Normal conditions, good growth
Glycogen (liver, muscle)	Chronic stress, dietary problems	Liver damage, diet too high in carbohydrate
Hematocrit (blood)	Anemia, hemodilution	Hemoconcentration, gill damage
Hemoglobin (blood)	Anemias	Hemoconcentration, gill damage
Hemoglobin (mucus)	No recognized significance	Acute stress
Interrenal hypertrophy	No recognized significance	Chronic stress
Lactic acid (blood)	Normal conditions	Acute or chronic stress, muscular exertion
Osmolality (plasma)	External parasites, heavy metals, hemodilution	Dehydration, impaired osmoregulation
RNA/DNA (muscle)	Impaired growth, chronic stress	Normal conditions
Total protein (plasm)	Infection, nutritional problems, renal failure	Hemoconcentration

the direct result of increased susceptibility to infectious fish diseases (Wedemeyer and Goodyear 1984). At the population level, effects on the health and physiological quality of individual fish that result in reduced survival, growth, or reproduction potential will ultimately be manifested as decreased recruitment to succeeding life stages (Goodyear 1980). Unfortunately, population responses can be difficult to use in establishing cause and effect relationships with rearing conditions because of the time delay and because the nature, intensity, and timing of the mechanisms that influence the ocean survival of juvenile salmonids after release are poorly understood (Goodyear 1980).

Of all the effects of rearing conditions on fish health, susceptibility to infectious fish diseases has probably received the most attention (Wedemeyer and Goodyear 1984). Experience has shown that simple exposure to fish pathogens, unless they are present in overwhelming numbers, does not necessarily result in epizootics unless unfavorable environmental conditions and a compromised host defense system occur simultaneously. Thus, fish diseases are not single-caused events, but are only one outcome of the continuing interactions among the infectious agent, chemical and physical conditions in the aquatic environment, and the physiological systems of the host (Sniesko 1974). If the fish-environment-pathogen relationship is favorable, good health, growth, and survival will occur; if it is marginal, fish health will deteriorate, infectious diseases will begin to occur, and reduced physiological quality, growth, and survival will result. If the relationship is unbalanced in favor of the pathogen, chronic fish disease problems can be expected (Wedemeyer and Goodyear 1984). The infectious diseases that experience has shown to have the most promise as early warning indicators that rearing conditions have become stressful are those due to facultative bacterial fish pathogens such as aeromonads, pseudomonads, and myxobacteria, which are ubiquitous in surface water supplies. A classic example is myxobacterial gill disease, which frequently resists drug treatment until the fish loading density in the ponds is also reduced. Other stress-mediated fish diseases include *Yersinia ruckeri* infections, *Vibrio anquillarum*, aeromonad and pseudomonad hemmorrhagic septicemias, and parasitic and fungal infestations such as costiasis (*Icthyobodo*) and *Saprolegnia* (Hunter et al. 1980; Wedemeyer and Goodyear 1984). A summary list of stress-mediated diseases, together with a description of adverse rearing conditions implicated in their occurrence, is given in Table 3.

In addition to affecting resistance to infectious diseases, rearing conditions can also adversely affect the normal development of smoltification. Seemingly harmless fish loading densities and alterations in water chemistry, temperature, or photoperiod during freshwater rearing may inhibit one or more aspects of the parr-smolt transformation and lead to impaired early marine survival after release (Fagerlund et al. 1983, 1984). For example, the normal development pattern of the gill ATPase enzyme system of coho salmon (*Oncorhynchus kisutch*) parr is affected by alterations in water temperature and by otherwise sublethal amounts of dissolved heavy metals such as copper. The consequence is loss of osmoregulatory function, reduced physiological tolerance to sea water, and thus reduced early marine survival. An equally significant consequence is the inhibition of normal migratory behavior.

In addition to trace heavy metals, contaminants such as the herbicides and nitrates now common in surface waters as the result of intensive agriculture can affect the parr-smolt transformation. These effects, which are otherwise sublethal to individual fish, have serious population-level implications.

Performance Challenge Tests

Performance challenge tests offer particular potential as methods for determining the effects of hatchery rearing conditions on fish health and physiological quality. These are based on the presumptions that (1) otherwise sublethal environmental stress of sufficient magnitude or duration eventually becomes debilitating and affects health and physiological quality, and (2) the effect of multiple stress factors is cumulative. To the extent that reduced health and physiological quality impairs growth, survival, or reproduction of enough individual fish, the survival probability of the population as a whole is reduced.

At present, performance challenge tests are at an early stage of development, and little agreement exists on the most suitable approaches. Selected tests are presented here, together with a brief discussion.

Table 2. Hematological and clinical chemistry ranges for blood tissue chemistry values that can be expected in clinically healthy juvenile coho salmon and rainbow trout under average hatchery conditions: soft water, 10°C, OMP diet (compiled from Hille 1981 and Wedemeyer and McLeay 1981).

Physiological parameter	Coho salmon	Rainbow trout
Ascorbate, interrenal (μg/g)		102-214
Bicarbonate (meq/L)	9.5-12.6	8.9-15.9
Bilirubin (mg/dL)		0.4-4.5
Blood urea nitrogen (mg/dL)	0.9-3.4	0.9-4.5
CO_2 (volume %)	24-28	
Calcium (mg/dL)		6.7-10.6
Chloride (meq/L)	122-136	84-132
Cholesterol (mg/dL)	88-262	161-365
Clotting time (s)		
Aorta canula		150-250
Cardiac puncture		50-150
Severed caudal peduncle		20-60
Cortisol (μg/dL)		1.5-18.5
Erythrocytes (10^6/mm^3)	0.7-1.7	0.6-1.3
Glucose (mg/dL)	41-135	41-151
Hematocrit (%)	22-44	24-43
Hemoglobin (g/dL)	6.5-9.9	5.4-9.3
Leukocytes (1,000/mm^3)		5.4-36.0
Magnesium (meq/L)		1.2-3.3
Osmolality (m°SM)		288-339
pH (10°C)		7.5-7.83
Phosphorus (mg/dL)	5.1-12.0	8.4-12.7
Thrombocytes (1,000/mm^3)		11.-21.0
Total protein (g/dL)	1.4-4.3	2.-6.0

Table 3. Fish diseases that are stress-mediated and have potential as indicators in biological monitoring for environmental quality.

Fish disease problem	Predisposing environmental factors
Bacterial gill disease (*Flavobacteria* sp.)	Crowding; chronic low oxygen (4 mg/L for salmonids); elevated ammonia (more than 0.02 mg/L for salmonids); excessive particulate matter in water
Blue sac, hydrocele	Temperature, ammonia, crowding
Columnaris (*Cytophaga columnaris*)	Crowding or handling during warm water periods if carrier fish are present
Environmental gill disease	Adverse rearing conditions, but contributory factors currently not well defined
Epithelial tumors, ulceration	Chronic, sublethal contaminant exposure
Fin erosion	Crowding; low dissolved oxygen; nutritional imbalances; chronic exposure to trace contaminants; high total suspended solids; secondary bacterial invasion
Furunculosis (*Aeromonas salmonicida*)	Low oxygen (4 mg/L for salmonids); crowding; handling if pathogen carriers are present
Hemorrhagic septicemias, red-sore disease (*Aeromonas, Pseudomonas*)	External parasite infestations; inadequate pond cleaning; crowding; elevated ammonia; low oxygen; stress due to elevated water temperatures; handling after overwintering at low temperatures
Kidney disease (*Renibacterium salmoninarum*)	Water hardness less than about 100 mg/L (as $CaCO_3$); diet composition
Nephrolithiasis	Water high in phosphates and carbon dioxide
Parasite infestations	Overcrowding of fry and fingerlings; low oxygen; excessive size variation among fish in ponds
Skeletal anomalies	Chronic, sublethal contaminant exposure, adverse environmental quality, PCB, heavy metals, Kepone, Toxaphene exposure, dietary vitamin C deficiency
Spring viremia of carp	Handling after overwintering at low temperatures
Strawberry disease (rainbow trout)	Uneaten feed, fecal matter with resultant increased saprophytic bacteria, allergic response
Sunburn	Inadequately shaded outside raceways, dietary vitamin imbalance may be contributory
Swim bladder stress syndrome	Environmental stress; temperature, light, salinity, other water quality
Vibriosis (*Vibrio anquillarum*)	Handling; dissolved oxygen lower than about 6 mg/L, especially at water temperatures of 10–15°C; salinity of 10–15%.
White spot, coagulated yolk disease	Environmental stress: supersaturation > 102–103%, temperature, metabolic wastes, chronic trace contaminant exposure.

Reduced Temperature Tolerance

The effects of rearing conditions on ability to tolerate water temperature changes are of fundamental importance during the hatchery phase and after fish are released. Thus, thermal challenge tests to determine whether prior stress has reduced the ability to mount a compensatory physiological response, or simply to determine if temperature tolerance limits have been narrowed (Becker and Wolford 1980; Bonin 1981; Watenpaugh et al. 1985) can provide highly significant information.

Tolerance to Hypoxia

The ability to withstand an oxygen depletion was originally proposed as a rapid, simple physiological challenge test to evaluate the effects of otherwise sublethal contaminant exposure on fish health and quality (Vigers and Maynard 1977). Such tests have since been applied successfully in identifying sublethal effects on the health of marine as well as freshwater fish and in field monitoring surveys to determine the zones of influence of water quality alterations within receiving waters.

Swimming Performance

Effects on swimming ability have long been used as a way to relate rearing conditions to fish health and physiological quality (Beamish 1978). The measurement of swimming performance typically involves determining critical swimming speed, fatigue time (endurance), swimming efficiency, or performance rating.

Unfortunately, differing fish-cultural practices rearing conditions may have little effect on the swimming performance ratings obtained. Although short-term exposure to adverse water quality frequently impairs swimming performance, chronic exposure may result in normal or even increased stamina. This return to normal swimming performance may occur even when growth has been inhibited and gill pathology or other evidence for a state of chronic stress is apparent. Apparently, chronic adverse rearing conditions, particularly if hypoxias is involved, may result in the compensatory development of a more efficient cardiorespiratory system that yields swimming performance equal to or better than that of unstressed controls. Changes in the normal decrease in swimming efficiency during smoltification, which is based on tail-beat frequency versus swimming speed (body lengths/s), may ultimately prove to be a more useful measure of the effects of rearing conditions (Besner and Smith 1983; Flagg et al. 1983).

Scope for Activity

The difference between the oxygen consumption of fish at rest and undisturbed (standard rate), and the oxygen consumption of fish swimming at maximum sustained speed (active rate) is defined as "scope for activity." The bioenergetic cost of chronic or acute stress, as indicated by decreased scope for activity, provides a means for assessing impacts on physiological quality in terms of the energy remaining for activity and growth (Priede 1985). Fish affected by stressors may either show an increased standard metabolic rate or a lowered active metabolic rate. The net effect is to reduce the scope for activity. Water quality changes that adversely affect respiration strongly affect scope. Thus, scope for activity tests easily detect rainbow trout reared in recycled hatchery water.

Scope for activity can also be used to compare the tolerance of fish species, or genetic strains within species, with changes in temperature, photoperiod, and food supply. Effects on scope for activity may also be used to determine the tolerance of anadromous fishes to rearing in brackish water in estuarine areas. Information on the effects of a wide range of rearing conditions on scope for activity would greatly assist in developing the biological information required to correctly assess the effects of fish-cultural practices on the physiological quality of anadromous salmonids during freshwater rearing.

Fish Disease Challenge Tests

The stress of unfavorable rearing conditions can predispose juvenile anadromous fish to infectious diseases in freshwater and in the marine environment after release (Wedemeyer and Goodyear 1984). Thus, the use of standardized disease challenge tests to evaluate the stress of hatchery practices or other environmental conditions has considerable merit. Improved information on the point at which multiple hatchery stress factors begin to exceed physiological tolerance

limits and compromise disease resistance is especially needed.

Reduced Tolerance to Reference Toxicants

Although decreased tolerance to toxicant exposure under standardized conditions is not used at present as a method to evaluate the effects of rearing conditions on fish health and physiological quality, this approach has some potential as a practical test procedure. For example, goldfish (*Carassius auratus*) with parasite infestations have reduced tolerance to standardized sodium chloride exposure. Phenol challenge will differentiate unstressed rainbow trout from others that have been stressed by fasting, adverse temperatures, or sublethal chlorine exposure. However, fish subjected to crowding stress will tolerate a subsequent phenol challenge as well as unstressed controls. Similarly, resistance to sodium dodecyl sulphate exposure is not reduced by the stress of hauling and handling.

The single response (death) measured by challenge with a reference toxicant is unlikely to reveal more than general information about effects of rearing conditions on the physiological quality of anadromous salmonids. However, reference toxicant challenges may prove to be of value in selected instances. Standardized rearing and challenge conditions will be required to establish a baseline from which comparison can be made.

Salinity Challenge Tests

The ability to tolerate increased salinity is now receiving considerable attention as a method of evaluating effects of rearing conditions on the normal physiological development of juvenile anadromous salmonids (Clarke 1982). A 24-h seawater challenge test at a salinity of 30 ppt will detect incipient osmoregulatory dysfunction or elicit a generalized stress response or both, either of which can be used as an indicator of health and physiological quality (Blackburn and Clarke 1987). Three biological end points are commonly used in salinity challenge tests: 24–96 h survival, ability to regulate blood sodium to 170 mEq/L or lower within 24 h, or growth and survival for a 3- to 6-month period. For some anadromous salmonids, such as coho salmon, chinook salmon (*O. tshawytscha*), and steelhead (*O. mykiss*), failure to regulate blood sodium below 170 mEq/L following seawater challenge can reveal the existence of latent infections, effects of prior fish disease treatments, and effects on physiological quality from otherwise sublethal rearing conditions. Salinity challenge tests at 35 ppt are being used to determine tolerance of migrating smolts to the stress of fish-passage facilities at Columbia River dams (Matthews et al. 1986). Such tests also have potential for assessing delayed effects of stress from rearing conditions on migrating smolts after hatchery release.

Tolerance to Crowding

Crowding, or exceeding the carrying capacity of the water, is one of the most common rearing conditions encountered by hatchery fishes. Crowding can also easily be used as a challenge test. Crowding juvenile anadromous salmonids consistently elicits a moderate to severe physiological stress response, which then may be used to provide useful information on health and quality (Barton et al. 1980). To conduct a crowding stress challenge test, groups of fish to be tested are acclimated to lightly loaded conditions for a 2-week period; typically a loading density of 0.04 kg/L or less is adequate. The fish are then challenged by increasing the loading density to 0.2–0.6 kg/L, usually for a 24-h period. Blood samples from groups of 10 fish are taken at 0, 4, 6, 24, 48, and 72 h and analyzed for glucose and chloride. A semiquantitative estimate of the severity of the resulting physiological stress response and the time needed for recovery can be obtained from a graph of the results by measuring or calculating the area under the hyperglycemic or hypochloremic response curve (with a planimeter). Although blood glucose and chloride have among the lowest coefficients of variation of all physiological parameters, test conditions such as anesthetic and blood sampling method must be standardized and the water exchange rate must be high enough to keep the dissolved oxygen near saturation and the un-ionized ammonia below about 0.02 mg/L.

Together with other appropriate measuring of fish health and quality, use of the physiological tests and performance challenge procedures discussed above should assist in identifying fish cultural practices and rearing conditions needed to improve the health, quality, and early marine survival of juvenile anadromous salmonids released from rearing facilities.

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Nutritional Requirements of Anadromous Fishes

by

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Abstract. The nutritional requirements of a number of intensively cultured anadromous fish species are summarized, primarily salmonids, sturgeons, and striped bass. In general, these fishes have protein requirements in the range of 30% to 50% of the diet and have been reared successfully with crude lipid levels as high as 12% to 25% of the diet. Fatty acid requirements are usually limited to the longer-chain members of the linolenic or n-3 family, but many species may require polyunsaturated members of the linoleic or n-6 family. Requirements by anadromous fishes have either been demonstrated or assumed for all of the amino acids, vitamins, and several minerals that are required in the diet by all other vertebrate animals. Information is presented on the interaction of several macronutrients and micronutrients in diet formulations and on effects of research on nutritional requirements.

Worldwide production by commercial aquaculture is about 13 million metric tons and is valued at more than $19 billion annually (Fish Farming International 1990 17:1). As intensive methods of fish culture become the method of choice, proper nutrition and scientifically formulated feeds for all aquaculture species will become increasingly important. Advances in this field have been slow but may now be expected to progress more rapidly. The U.S. Fish and Wildlife Service has an extensive history of involvement in fish culture research and has long been a world leader in this field. Several Service facilities conduct full-time nutrition research, including the Tunison Laboratory of Fish Nutrition and the Lamar Fish Technology Center in Pennsylvania, the Abernathy Salmon Cultural Center and the now defunct Western Fish Nutrition Laboratory in the State of Washington, and the Bozeman Fish Technology Center in Montana. The Service strives to maintain its leadership in fish nutrition science and to provide this information to the global community.

The primary goal of aquaculture is production of various aquatic species for either food or restoration. Accordingly, the main objective of fish nutrition research is assistance with the conversion of fish food to fish flesh by the most rapid, economical, and efficient means. Such feed must contain all essential nutrients in the proper amounts to meet the nutritional needs of fishes.

The major nutrient groups are the same for fish as for other animals and include proteins and amino acids, fats and fatty acids, vitamins, minerals, water, and a variety of other components, including fiber (water and other components will not be addressed in this paper).

Protein and Amino Acid Requirements

The protein requirements shown in Table 1 for various life stages of rainbow trout, channel catfish, eel, and carp reflect the concept that protein requirements decreases with age of the fish. Fry have the

highest protein requirements, fingerlings and subadults have a slightly lower protein requirement, and adults have the lowest protein requirement. This decrease in protein requirement is assumed to be a function of the increased ability of the adult fish to utilize proteins efficiently and the decreased demands for dietary protein to support growth. The dietary protein requirements for anadromous fish species (Table 2) tend to be between 40% and 50% of the diet. All of the studies were conducted with high quality proteins such as casein or good quality fish meals. These proteins are assessed to provide all of the required amino acids and therefore to meet optimal protein requirements.

Established amino acid requirements for several anadromous salmonid species (Table 3) reflect the paucity of existing knowledge about amino acid requirements for even the most commonly cultured fish species. Amino acid requirements have been determined for only five species of anadromous fishes, and only the requirements for the rainbow trout have been determined by more than one investigator. Lack of data is the result of the high cost of and profound demands on time by research. Scarcity of workers in fish nutrition likewise precludes rapid closure of informational gaps. Development of comprehensive information about nutritional requirements for all species is a priority in aquaculture.

Table 1. Recommended protein levels of practical fish diets (given as percent on as-fed basis)

[These levels are given only as general guidelines because protein sources and amount of dietary fat greatly affect the optimal level of dietary protein.]

Species	Fry to fingerlings	Fingerlings to subadults	Adults
Rainbow trout	50 - 55	40 - 50	30 - 40
Channel catfish	35 - 40	25 - 36	25 - 32
Eel	50 - 56	45 - 50	
Carp	43 - 47	37 - 42	28 - 32

Table 2. Estimated dietary protein requirements of some species of juvenile fish

Species	Protein source	Estimated protein requirement (percent)	Reference
Arctic charr	Fishmeal	-40	Jobling and Wandsvik 1983
Chinook salmon	Casein, gelatin, and amino acids	40	DeLong et al. 1958
Coho salmon	Casein	40	Zeitoun et al. 1974
Japanese eel	Casein and amino acids	-45	Nose and Arai 1972
Rainbow trout	Fishmeal	40	Satia 1974
	Casein and gelatin	40	Zeitoun et al. 1973
	Casein, gelatin, and amino acids	45	Halver et al. 1964
Sockeye salmon	Casein, gelatin, and amino acids	45	Halver et al. 1964
Striped bass	Fishmeal and soy proteinate	47	Millikin 1983
White sturgeon	Casein, egg white, and wheat gluten	-40	Moore et al. 1988

Table 3.--Comparative amino acid requirement (expressed as a percent of protein) of several juvenile anadromous species

[In parentheses, the numerators are the requirement as a percent of the diet, and the denominators are percent total protein in the diet]

Amino acid	Chinook salmon[a]	Coho salmon[b]	Chum salmon[c]	Rainbow trout[d]	Japanese eel[e]
Arginine	6.0 (2.4/40)	5.8 (2.3/40)	(2.6/40)	3.3–5.9 (1.2–2.8/33–47)	4.5 (1.7/38)
Histidine	1.8 (0.7/40)	1.8 (0.7/40)	1.6 (0.7/40)		2.1 (0.8/38)
Isoleucine	2.2 (0.9/41)		2.4 (1.0/40)		4.0 (1.5/38)
Leucine	3.9 (1.6/41)		3.8 (1.5/40)		5.3 (2.0/38)
Lysine	5.0 (2.0/40)		4.8 (1.9/40)	3.7–6.1 (1.3–2.9/35–47)	5.3 (2.0/38)
Methionine	4.0 (1.6/40)		3.0 (1.2/40)	2.2–3.0 (1.0-1.1/35-46)	3.2 (1.2/38)
Phenylalanine	5.1 (2.1/41)		6.3 (2.5/40)		5.8 (2.2/38)
Threonine	2.2 (0.9/40)		3.0 (1.2/40)		4.0 (1.5/38)
Tryptophan	0.5 (0.2/40)	0.5 (0.2/40)	0.7 (0.3/40)	0.5–1.4 (0.3–0.6/42–45)	1.1 (0.4/38)
Valine	3.2 (1.3/40)		3.0 (1.2/40)		4.0 (1.5/38)

[a]Data from Halver et al. (1959), DeLong et al. (1962), Chance et al. (1964), Halver (1965), and Klein and Halver (1970).

[b]Data from Halver (1965), and Klein and Halver (1970).

[c]Data from Akiyama et al. (1985), and Akiyama (1987).

[d]Data from Kaushik (1979), Kim and Kayes (1982), Walton et al, (1982, 1984, 1986), Ketola (1983), Kim et al. (1983, 1984), Poston and Rumsey (1983), Rumsey et al. (1983), and Oho et al. (1989).

[e]Data from Nose (1979).

Vitamin Requirements

Vitamin requirements for the growth of anadromous fishes (Table 4) are known for salmon (chinook and coho) and trout (rainbow, brook, and brown). The requirements of these two groups are fairly similar. Minor differences are attributable either to differences in laboratory procedures or to improved experimental diets in more recent studies.

Choline and vitamin C have received much research attention recently in this country and in Europe. Results indicate that a significant portion (possibly up to 50%) of the metabolic need for choline by fish may be met by the quaternary-ammonium compound betaine, which is an oxidative product of choline (Rumsey 1988). Betaine may also function as a feeding stimulant and may facilitate the parr-smolt transition and the ability of smolts to osmoregulate in seawater. Vitamin C research has had renewed interest in recent years because of several protected products and derivatives, for example, the 2-sulfated and phosphorylated forms of the vitamin. Vitamin C is one of the most liable of all nutrients, its inclusion in the diet in a crystalline form has been one of the primary factors dictating the short shelf-life of fish feeds. With the introduction of several coated or stabilized forms of vitamin C, however, feed shelf-life may be lengthened, and several nutritional problems that resulted from the lack of vitamin C in the diet may be obviated (Halver et al. 1975; Tucker and Halver 1986; Dabrowski and Kock 1989; Grant et al. 1989).

Table 4. Determined vitamin requirements for growth of anadromous fishes (mk/kg dry diet)[a]

Vitamin	Salmon[b]	Trout[c]
Vitamin A (IU)	2,500	2,000-15,000
Vitamin D (IU)	2,400	2,400
Vitamin E	30-50	10
Vitamin K	10	10
Biotin	1-1.5	1-1.5
Choline	600-3,000	50-3,000
Folacin	5-10	5-10
Inositol	300-400	200-500
Niacin	150-200	1-150
Pantothenic acid	40-50	10-50
Riboflavin	20-25	3-30
Thiamin	10-15	10-12
Vitamin B_6	10-20	1-15
Vitamin B_{12}	0.015-0.019	0.02
Vitamin C	100-150	100-500

[a]Data adapted from National Research Council (1981, 1983).

[b]Chinook and coho salmon.

[c]Rainbow, brook, and brown trout.

Mineral Requirements

Requirements for essential mineral elements are no different for anadromous fishes than for other animal species and consist of 7 macroelements and 14 trace or microelements (Table 5). The division between the two groups is a function of the required amount of the mineral by an organism. Macro-elements are required at levels of 0.5 g or greater per kilogram of diet, whereas microelements are required at levels less than this amount. The actual metabolic requirement for some of the elements, calcium, for example, can be met through direct absorption of the mineral from the water by the gills. When fishes are reared in water with a high mineral content, there may be no need for the addition of these minerals to the diet. Several of these minerals, including chlorine, iron, copper, zinc, and iodine, can be toxic in excess.

Table 5. The essential mineral elements

Macroelements	Trace or microelements	
Calcium	Manganese	Cobalt
Phosphorus	Iron	Molybdenum
Magnesium	Copper	Selenium
Sodium	Iodine	Chromium
Potassium	Zinc	Tin
Chlorine	Fluorine	Nickel
Sulfur	Vanadium	Silicon

Fatty Acid Requirements

Fat is a source of readily available energy, and, moreover, the source of fatty acids for fishes. The fatty acids of concern fall into two groups: the $\geq$ 18-carbon fatty acids, which make up the linoleic (n-6) fatty acid series, and the linolenic (n-3) series. These fatty acids are required in the range of about 0.5% to 2% of the diet (Table 7). Some species may have a requirement for the linoleic series, but at this time most formulation concerns seek to meet only the n-3 requirements.

Table 6. Summary of mineral requirements of fish[a]

Mineral element	Requirement per kg dry diet
Calcium	5 g
Phosphorus	7 g
Magnesium	500 mg
Sodium	1–3 g
Potassium	1–3 g
Sulfur	3–5 g
Chlorine	1–5 g
Iron	50–100 mg
Copper	1–4 g
Manganese	20–50 mg
Cobalt	5–10 mg
Zinc	30–100 mg
Iodine	100–300 mg
Molybdenum	(trace)
Chromium	(trace)
Fluorine	(trace)

[a]Data adapted from National Research Council (1981, 1983).

Table 7. Essential fatty acid requirements of anadromous fish

Species	Requirement
Chum salmon[a]	1% 18:2n–6 and 1% 18:3n–3
Coho salmon[b]	1–2.5% 18:3n–3
Rainbow trout[c]	1% 18:3n–3 0.8% 18:3n–3 or 20% of lipid as 18:3n–3 10% of lipid as 20:5 (n–3) and 22:6 (n–3)

[a]Data from Takeuchi et al. (1979).

[b]Data from Yu and Sinnhuber (1979).

[c]Data from Castell et al. (1972), Watanabe et al. (1974), and Takeuchi and Watanabe (1977).

Data for other fishes, such as striped bass, are becoming available and indicate that requirements are not the same as those for salmonids. Evidence is accumulating that these fish are not capable of elongating the 18-carbon chain of the n-3 fatty acids to form

longer-chain, highly unsaturated fatty acids. Consequently, these fatty acids may have to be provided in the feed. Some data are shown in Table 8, wherein fatty acid analyses were conducted on *Artemia*, which can be used as a first food for striped bass larvae reared in hatcheries. The amount of 20:5 and 22:6 n-3 fatty acids is very small in the sampled *Artemia*. Analyses of striped bass larvae fed pond-reared zooplankton, however, show very high levels of these fatty acids. Very low levels of 20:5 and 22:6 n-3 fatty acids in tissues of striped bass that were fed *Artemia* indicate the diet was deficient in these fatty acids and that the larvae could not fabricate them. This type of evidence supports the assumed requirement for the longer-chain, highly unsaturated fatty acids, and concern for supplying these nutrients will become increasingly important as species such as striped bass, red fish, and the European sea bass become more prominent in aquaculture. These data also show that *Artemia* apparently cannot elongate and desaturate the 18:3 n-3 fatty acid.

Nutrient Interactions and Availabilities

A number of nutrient interactions are of concern during diet formulation. One interaction involves the mineral ash content of fish meal. In the early 1970's, the predominant fish meals in aquaculture feeds were either whole-herring or whole-anchovy meals. With the demise of the Chilean anchovy fishery in the early 1970's and decreased availability of whole herring because of increased governmental regulation and increased use in human foods and feeds for other animals, alternative fish meals had to be sought. The choice was white fish meal, which is that made from the carcasses of various fish species after the fillets have been removed. This blended fish meal is lower in protein than the whole-anchovy or whole-herring fish meals and also contains a significantly higher ash content because of the higher amount of bone. Salmonids on white fish meal diets developed bilateral lenticular cataracts and exhibited poor growth characteristics. Research (Ketola 1979; Ogino and

Table 8. Fatty acid composition of *Artemia* and striped bass larvae[a]

Fatty acid	*Artemia*	Zooplankton-fed larvae	*Artemia*-fed larvae
14:0	0.60	1.32	1.10
14:1	1.89		1.29
15:1	0.67	0.04	0.46
16:0	11.80	20.70	13.20
16:1	6.68	6.18	7.56
16:3 W 4	1.20		1.19
18:0	5.09	11.09	6.37
18:1 W 9	23.67	16.12	24.03
18:2 W 6	8.48	2.25	9.18
18:3 W 3	28.84	4.76	22.49
18:4 W 3	7.28	0.71	5.08
20:0	0.80	0.17	0.84
20:3 W 3	0.15	0.12	0.28
20:3 W 3	1.47	3.56	2.32
20:5 W 3	0.07	6.78	1.50
22:1	1.14	0.38	1.65
22:4 W 6	0.16	0.92	0.21
22:3 W 3		0.65	0.12
22:6 W 3		23.56	1.08
24:1		0.37	
Total	99.99	99.98	100.01

[a]Information provided by Dr. G. Kramer, EA Science and Technology, Middletown, N.Y.

Yang 1978) revealed that the high ash content of the fish meal caused chelation of the zinc and made it totally unavailable to the fishes. Therefore, although the diets contained more than adequate levels of zinc, fishes on these diets experienced zinc deficiency. This problem can be alleviated by adding at least 150 pm supplemental zinc to the diet, but the incident illustrates the need for more information on nutrient availabilities and interactions of nutrients and the potential consequences of conclusions based on sample calculations or chemical analysis.

Another important interaction of nutrients is the antagonistic reaction among the various branched-chain amino acids (leucine, isoleucine, and valine) when they are incorporated at excessive levels in the diet (reviewed by Hughes 1984). Diets with significant amounts of corn products are particularly prone to these antagonistic relationships. Research revealed that excessive levels of leucine or isoleucine may increase the requirement for the other branched-chain amino acids and may also impact on threonine nutrition. Excessive levels of valine, in turn, may cause toxicity that cannot be alleviated by increasing the dietary amounts of leucine or isoleucine.

Another concern in amino acid nutrition is the form in which the amino acid is provided in the diet. For example, methionine is available in various stabilized forms and several analogues. Studies by Poston (1986) revealed that availabilities of these forms vary tremendously and cannot be randomly substituted into the feed in amounts that seem to be of equal nutrient levels.

Many substances can be categorized as antinutrients, most notably the trypsin inhibitor found in soybean meal. Raw soybeans contain crystalline globular proteins that act as trypsin inhibitors (Mickelsen and Yang 1966; Liener and Kakade 1980). These proteins have a molecular weight of about 21,500 and form irreversible complexes with trypsin. The trypsin inhibitor can be inactivated to a certain extent through autoclaving or heat processing the raw soybeans (Ham and Sandstedt 1944), but excessive heat treatment reduces the availability of certain amino acids, particularly lysine. The growth inhibition of soybean products for fingerling rainbow trout (Sandholm et al. 1976; Smith 1977) has been presumed to be due to interference with protein utilization, but several other studies (Ketola 1975; Rumsey and Ketola 1975; Dabrowska and Wojno 1977) indicate that nutrient deficiencies or other antinutritional factors in the soybeans may also contribute to the growth depression of fishes on soybean meal-based diets.

Trypsin inhibitors have also been found in lima beans (Klose et al. 1949), raw chicken egg whites (Chatterjee and Montgomery 1962), and sweet potato (Sheu 1979), but the amounts vary significantly (e.g., whole wheat four contains only about 1% of the trypsin inhibitor activity of whole soybean meal; Shyamala and Lyman 1964). Only trypsin inhibitors from soybeans, however, are of major concern to fish culturists at this time because of the extensive use of soybeans in fish feeds. Sensitivity of various fish species to trypsin inhibitors varies, and salmonids are the most sensitive (Sandholm et al. 1976; Smith 1977). Dietary protein levels may have a direct effect on the sensitivity of the inhibitor (Wilson and Poe 1985).

Another anti-nutrient of major concern is thiaminase, which is present in the flesh of a number of fish species. The thiamin-destroying enzyme thiaminase has long been known to be present in some raw fish preparations (Green et al. 1941; Wooley 1941; Wolf 1942; Deutsch and Hasler 1943; Lieck and Agren 1944; Yudkin 1946; Neilands 1947). Species with or without thiaminase were reviewed by the National Research Council (1983). The enzyme is found more commonly in freshwater fishes and has also been found in rice polishings, beans, and mustard seeds (Goldsmith 1964). Thiaminase can be inactivated by heat (Wooley 1941), but heat application must be adequate to eliminate all activity of the enzyme system. The thiamin content of prepared diets is only destroyed after contact for a period with the thiaminase of raw fish or other thiaminase-containing foodstuffs. The thiamin requirement by fishes can be met by alternately feeding moist feed with raw fish and a second diet that is high in thiamin but has no thiaminase-containing raw fish. This is an alternative solution to heat-processing raw fish to destroy the thiaminase. This problem can only be avoided by careful screening of the fish species in the fish diets and the elimination of those containing thiaminase.

Diet Formulations

Several diet formulations are commonly fed to anadromous fishes in the United States (Table 9). The Abernathy starter and pellet diets were developed for Pacific salmonids and have also been used for several other species. The OP-2 formulation is a grower for-

mulation that is unique because it contains a wet fish mix made from whole or scrap fish. Thiaminase may become a problem in this type of formulation if the wrong fish species are included in the wet mix. The ASDA-30 diet, which was developed for Atlantic salmon, has also been used in striped bass aquaculture. All of these diets utilize relatively high-quality and highly digestible ingredients and, with the exception of the OP-2 diet, contain protein levels of 45% to 55%. The OP-2 diet is a grower-type ration for sub-adults and adults and therefore does not have the high protein levels of diets for fry and fingerlings. Further examination of the diets fed to fry reveals that they contain high (greater than 15%) levels of fat and very low levels of fiber and ash.

Table 9. Salmon feeds – Oregon-moist pellet (OP-2), Abernathy salmon, and ASD2-30 diets[a]

	Diet			
	Abernathy starter	Abernathy pellets	OP-2	ASDA-30
Formulation (% composition)				
Fish meal	58	50	28	50
Dried whey	10	10	5	
Blood flour	5	5		10
Soy flour				20.3
Shrimp meal	5	5	4	5
Brewers yeast	5	5		
Wheat middlings	3	14		
Cottonseed meal			15	
Wheat germ meal			6	
Corn distiller dried solubles			4	
Wet mix (whole fish or scrap)			30	
Fish oil	12	9	6	12
Ascorbic acid				0.075
Vitamin premix	1.5	1.5	1.5	0.4
Choline HC1 (70%)	0.5	0.5	0.5	
Mineral mix #2				0
Pellet binder				2
Proximate analysis (% net weight)				
Protein	50	47	32	53
Fat	18	15	10	16
Ash	13	12	8	12
Fiber	1.4	2.1	2	4
NFE	12.5	18.4	17	6
Energy (kcal/kg diet)				
Metabolic energy	4,173	3,724	2,554	3,849
Gross energy	5,110	4,883	3,550	4,916

[a]Table values from Piper et al. (1982).

In an attempt to minimize expenditures of time and money in development of feed for fishes, several techniques have been identified for estimation of amino acid requirements by fishes. One of these methods is the use of either the carcass or the egg amino acid profile of the fish species as an indicator of its amino acid requirements (Arai 1981; Ketola 1982; Ogata et al. 1983). The amino acids in the tissues or the eggs are assumed to be at or near the level required in the diet by that fish. If diets are formulated with these levels and ratios as minimum specifications, they should be at least adequate in the amino acids. This process was used in diets for Atlantic salmon (Table 10). A casein basal diet with 40% protein was fed as a control. This diet was then supplemented with crystalline amino acids to adjust the amino acid profile to the National Research Council (NRC) published amino acid requirements for salmonids, the carcass amino acid profile of the Atlantic salmon, the amino acid profile of a fish protein concentrate (FPC) derived from herring, or the amino acid profile of the Atlantic salmon egg. The diets supplemented with amino acids up to the level of the fish egg or of the FPC achieved a significantly lower mortality rate than the other diets, and the greatest increase in growth was obtained with the diet based on the amino acid profile of the egg.

Table 10. Weight gain and mortality of Atlantic salmon fed diets with amino acid supplements based on different criteria

Diet	Weight gain (g/fish)	Mortality (percent)
Casein-basal (40% protein)	2.4	60
+ AA (NRC)	3.0	62
+ AA (carcass)	3.1	64
+ AA (FPC-herring)	3.4	31
+ AA (egg)	4.1	11

Table 11 shows data where Atlantic salmon were fed a soybean-based diet, which was then supplemented with amino acids to simulate the profile of the trout egg. Inclusion of any one of the deficient amino acids did not significantly improve growth. When all five amino acids were included, restoring the proper amino acid balance, the increase in growth was significant.

Table 11. Growth of Atlantic salmon fed a soybean basal diet with and without supplemental amino acid to simulate profile of trout egg protein

Diet	Amino acid supplement	Weight gain (g/fish)
Soybean	None	12.0
-do-	+ Leu	12.2
-do-	+ Val	11.6
-do-	+ Thr	11.9
-do-	+ Met	12.3
-do-	+ Lys	11.4
-do-	+ all five AA	14.2

This process has also been used with rainbow trout (Table 12). The inclusion of various amino acid supplements to mimic the amino acid profiles of either the egg or FPC provided the greatest increase in growth. This refined and efficient technique has also been used with a number of other fish species, including striped bass in a cooperative research project between the Tunison Laboratory of Fish Nutrition and the Fish Culture Research Laboratory in West Virginia, and provides preliminary amino acid levels for use in diet formulation and a scientific basis for changes in diet formulation.

Factors Affecting Feed Selectivity

Six factors mediate feed selectivity by fishes: (1) feed particle size, (2) chemical constituents such as toxins or bitter components, (3) chemosensitivity of the fishes (if the animal is familiar with the chemical signals being given by the particular feed item it is more likely to consume that food item), (4) moisture content of feed, (5) texture of feed (including the moisture content), and (6) the specific gravity of the feed, which affects the rate at which the food pellet will fall through the water column. My research has involved identifying feeding stimulants. The four general characteristics of feeding stimulants are low molecular weight, nonvolatile, nitrogenous, and amphoteric (i.e., they contain basic and acidic functions at the same time). The main groups of compounds that meet these general criteria for fish chemostimulants are the amino acids, betaine (a quaternary ammonium compound related to choline), and several of the nucleotides, most notably inosine, which

Table 12. Growth of rainbow trout fed a soybean basal diet with and without supplemental amino acids

Diet	Amino acid profile	Amino acid supplement	Weight gain (g/fish)
Soybean	Soybean	None	4.2
-do-	NRC	Met	4.6
-do-	Carcass	His+Lys+Met	4.4
-do-	Egg	Met+Leu+Lys+Val+Thr	6.0
-do-	Herring FPC	Met+Leu+Lys+Val+Thr+His+Trp+Tyr	6.4

has been shown to hold some chemostimulatory properties, and homarine, a nucleotide specific to lobsters. I first examined whether chemical cues given off by the diet elicit a response from fishes. Fish have many receptors with which to smell or taste amino acids. Therefore, I examined whether amino acids leach out of the diet after immersion into water. Figure 1 shows the quantities of amino acids that have leached out of several common feed ingredients used in salmonid diets when these ingredients have been placed in water for 30 s. Each of the ingredients does have its own particular amino acid leachate "fingerprint" by which a fish may distinguish various substances from one another. Similar data have been obtained for complete diets, indicating that even at this level there are specific amino acid leachates for a specific diet. I have examined several items where the addition of amino acids or other ammonium containing compounds to the diet affect feed selectivity.

Table 13 shows the response of chinook salmon to a single feeding of a diet containing one of a number of ammonium-containing compounds. The compounds used were the amino acids alanine (Ala) and glycine (Gly), betaine (Bet) and trimethylamine (TMA). Trimethylamine is a degradation product that occurs in oxidized fish flesh and oil and may act as an indicator of rancidity. Addition of betaine or trimethylamine to the diet caused a significant decrease in feed intake, which supports the hypothesis that simple additions to the diet have a definite effect on feed consumption, even at the first feeding.

Table 13. Single feeding food consumption of chinook salmon fry fed diets containing potential feeding stimulants[a]

Diet description	Food consumption (mg/fish)
Control	3.12
+ Ala	2.51
+ Bet	*1.00
+ TMA	*1.55
+ Ala + Gly	4.04
+ Ala + Bet	3.27
+ Gly + Bet	2.99
+ Ala + Gly + Bet	2.82

[a]Data from Hughes 1993; asterisk indicates significant difference from the controls.

The addition of trimethylamine caused a decrease in food consumption similar to those in turbot (Mackie and Adron 1978) and plaice (Mackie 1982) on diets with this compound or its oxidation products. The salmon in my study may have been sensitive to this compound as an indicator of the "freshness" of the feed, and this sensitivity may play a role in the apparent aversion toward highly oxidized oils and fish meals by other salmonids (Hung and Slinger 1980; Ketola et al. 1989; Hughes 1993) and yellowtails (Murai et al. 1988). Betaine also caused a decrease in food intake. Several studies revealed that betaine is actually a feeding stimulant or elicits a response by fishes to an unfamiliar chemical signal that later will enhance feeding.

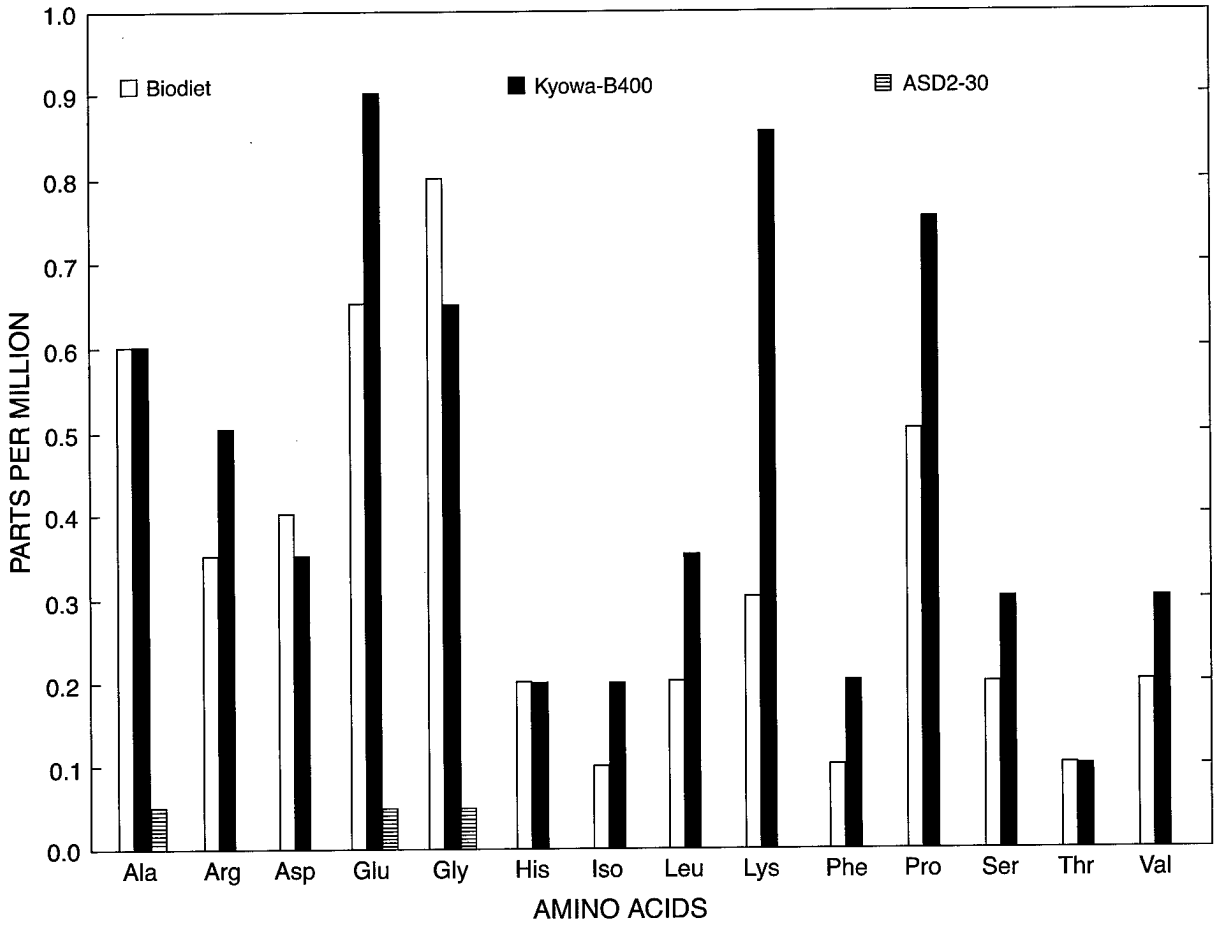

Figure 1. Quanities of amino acids leached into the water from several common salmonid diet formulations after 30 seconds of immersion.

Table 14. Comparison of growth of rainbow trout and Atlantic salmon fed diets supplemented with betaine and glycine

Treatment	Initial body weight (g)	Final body weight (g)	Percent increase over initial body weight	Feed/gain (g/g)
		Rainbow trout		
Basal	0.390	3.46	795	1.07
+ betaine	0.390	4.15	972	0.97
+ glycine	0.390	3.36	769	1.04
		Atlantic salmon		
Basal	1.900	8.42	443	1.94
+ betaine	1.900	10.42	572	1.52
+ glycine	1.900	7.72	402	2.19

Table 14 shows the results of feeding rainbow trout and Atlantic salmon diets containing either glycine or betaine. Over a 12-week period, the inclusion of betaine in the diet produced a significant increase in weight gain and an increase in the efficiency of feed utilization for both species. Betaine seemed to act as a feeding stimulant in these studies.

Conclusion

Much research remains to be done in the field of fish nutrition. There are many information voids that are now only filled with best guesses so that hatcheries and feed mills can function each day. Through sound, innovative research and a continued desire to provide the best possible aquacultural diets, we can continue forward and complete our understanding of the nutrition and physiology of cultured fish species.

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Appendix.--Common and scientific names of fishes cited in the text

Common name	Scientific name
Arctic char	*Salvelinus alpinus*
Atlantic salmon	*Salmo salar*
Brook trout	*Salvelinus fontinalis*
Brown trout	*Salmo trutta*
Channel catfish	*Ictalurus punctatus*
Chinook salmon	*Oncorhynchus tshawytscha*
Chum salmon	*Oncorhynchus keta*
Coho salmon	*Oncorhynchus kisutch*
Common carp	*Cyprinus carpio*
European sea bass	*Dicentrarchus labrax*
Japanese eel	*Anguilla japonicus*
Plaice	*Pleuronectes platessa*
Rainbow trout	*Oncorhynchus mykiss*
Red fish	*Sciaenops ocellatus*
Sockeye salmon	*Oncorhynchus nerka*
Striped bass	*Morone saxatilis*
Turbot	*Scophtahalmus maximus*
White sturgeon	*Acipenser transmontanus*
Yellowtail	*Seriola quinqueradiata*

Recent Advances in Detection and Control of the Principal Diseases of Pacific Salmon

by

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Abstract. Infectious diseases are the most important cause of mortality among stocks of Pacific salmon reared in hatcheries. Diseases caused by viruses, some bacteria, and the deep-tissue protozoans for which effective drugs, chemicals, or vaccines are not available are the greatest concern. For these untreatable diseases, the principal control measure is preventing contact between the host and pathogen. This paper reviews current methods for detection and control of the important pathogens of Pacific salmon and suggests future approaches that may prove useful.

Infectious diseases remain the single most important factor limiting the artificial propagation of salmonid fish. High rearing densities, adverse environmental conditions, and poorly designed culture systems lead to stressful situations that lower the natural resistance of the animals to infection. Disease in fish results from complex interactions between host, pathogen, and environment (Snieszko 1974). Whether this interaction results in disease or health depends on factors that include the species, stock, age, rearing density, and nutritional state of the fish; the strain, numbers, and virulence of the pathogen; and environmental variables such as temperature, water quality, water chemistry, and flow rate. In all cases, the most effective method for fish disease control is to prevent contact between fish and pathogen, which can be done by the use of pathogen-free water supplies, pathogen-free diets, good sanitation practices, and disease-free stocks. In addition to these measures, reducing mortality from fish disease relies on a combination of improving the environment, reducing the numbers of pathogens present, and increasing the resistance of the host (Wedemeyer et al. 1976; Ellis 1981; Ahne et al. 1989).

Recent advances in molecular biology have provided new tools for the rapid and sensitive detection of infectious agents and for the development of genetically engineered vaccines. For salmonids, new detection methods, based on the use of monoclonal antibodies and DNA probes, promise to be more rapid, sensitive, and cost-effective, while the genetic engineering of new types of vaccines will allow aquaculturists to rear fish that are more resistant to enzootic pathogens.

Fish Health Inspections

Many of the important viral, bacterial, protozoan, and fungal pathogens of Pacific salmon are listed in Table 1. In the western portions of North America, fish pathologists working for private, state, tribal, or federal agencies conduct extensive health examinations at several stages of the salmonid life cycle. These include routine checks to identify and avoid potential health problems, diagnostic examinations to identify pathogens as a basis for treatment, and specific-pathogen-free (SPF) certification exami-

nations required to be able to move fish to another location. In the United States and Canada, the methods used for these examinations have been standardized (Department of Fisheries and Oceans 1984; Amos 1985) and are outlined in Table 2. Many of the newer techniques in molecular biology are now being applied to the detection of fish pathogens and are expected to become common in the future (Fox et al. 1990).

Table 1. Important pathogens of Pacific salmon.

Viruses
Infectious hematopoietic necrosis virus
Viral hemorrhagic septicemia virus
Infectious pancreatic necrosis virus
Erythrocytic necrosis virus
Erythrocytic inclusion body syndrome virus
Herpesvirus salmonis
Oncorhynchus masou virus
Bacteria
Vibrio anguillarum
Vibrio ordalii
Aeromonas salmonicida
Aeromonas hydrophila
Pseudomonas sp.
Yersinia ruckeri
Cytophaga psychrophila
Flavobacterium sp.
Flexibacter columnaris
Renibacterium salmoninarum
Lactobacillus pisciola
Mycobacterium sp.
Protozoans
Myxosoma cerebralis
Ceratomyxa shasta
Myxobolus insidiosus
Costia necatrix
Hexamita salmonis
Proliferative kidney disease
Fungi
Saprolegnia sp.
Phoma herbarum

Table 2. Detection and identification of salmonid fish pathogens.

Viruses
• aseptically collect entire fry or samples of kidney, spleen, and other appropriate tissues from larger fish
• homogenize fry or tissues
• obtain ovarian or seminal fluid from adult fish
• centrifuge sexual fluids
• incubate samples in antibiotic mixture
• inoculate cultures of susceptible cell lines
• incubate at appropriate temperatures for at least 14 days
• observe cells daily for cytopathic effect
• subculture suspect samples
• confirm virus serologically by neutralization, fluorescent antibody, or enzyme-linked immunosorbent assay
Bacteria
• aseptically obtain material from kidney, other tissue, or lesion
• directly identify certain bacteria by Gram stain, fluorescent antibody
• inoculate appropriate bacteriological media
• incubate 3–28 days at appropriate temperature
• observe plates for growth
• identify bacteria morphologically biochemically, or serologically
Protozoans
• obtain appropriate material for examination
• prepare wet mounts for microscopy
• prepare tissues for histological examination
• identify protozoan morphologically or serologically
Fungi
• obtain appropriate material for examination
• prepare wet mounts for microscopy
• prepare tissues for histological examination
• identify fungus morphologically

Detection of Salmonid Fish Pathogens

Serological tests based on polyclonal antisera have long been used to identify fish pathogens (Department of Fisheries and Oceans 1984; Amos 1985). In recent years, enzyme-linked immunosorbent assays (ELISA) have been developed to create rapid and sensitive tests for direct detection of the antigens of *Aeromonas salmonicida* (Smith 1981; Austin et al. 1986; Adams 1988), *Yersinia ruckeri* (Austin et al. 1986), *Renibacterium salmoninarum* (Dixon 1987; Pascho and Mulcahy 1987), Infectious pancreatic necrosis virus (IPNV) (Nicholson and Caswel 1982; Dixon and Hill 1983; Hattori et al. 1984; Rodak et al. 1988), and Infectious hematopoietic necrosis virus (IHNV) and Viral hemorrhagic septicemia virus (VHSV) (Dixon and Hill 1984; Way and Dixon 1988). A dot blot ELISA, where antigens are spotted onto nitrocellulose paper and detected by labeled antisera, was reported by Sakai et al. (1987) for Bacterial Kidney Disease (BKD) and by McAllister and Schill (1986) for IHNV, VHSV, and IPNV.

Monoclonal antibodies are superior to polyclonal antisera for many applications because they are highly specific, very consistent, and do not cross-react with other antigens to any significant extent (Kohler and Milstein 1975). These advantages make it possible to improve the specificity and sensitivity of serological assays, allowing detection of very low levels of antigen in infected fish. Monoclonal antibodies (MAb's) have been developed against antigens of IHNV (Schultz et al. 1985; Winton et al. 1988; Ristow and Arnzen 1989), VHSV (Enzmann et al. 1988; Lorenzen et al. 1988), IPNV (Wolski et al. 1986; Lipipun et al. 1989), *Y. ruckeri* (Austin et al. 1986), *A. salmonicida* (Austin et al. 1986), *R. salmoninarum* (BKD) (Arakawa et al. 1987; Kaattari et al. 1987)), *Vibrio anguillarum* (Goerlich 1987), *V. salmonicida* (Esgelid et al. 1988), and *Ceratomyxa shasta* (Bartholomew et al. 1989).

Monoclonal antibodies have been used to detect IHNV antigen in cells and tissues of infected fish by immunofluorescence (La Patra et al. 1989), immunoblot (Schultz et al. 1989), immunohistochemical staining (Yamamoto et al. 1988), and ELISA (Parkyn and Littlepage 1988). Lorenzen et al. (1988) reported MAb's against VHSV were effective in detecting the virus by ELISA and immunofluorescence. A dot blot format was used by Caswell-Reno et al. (1989) to serotype IPNV and related aquatic birnaviruses. Austin et al. (1986) used MAb's to develop a rapid ELISA for detection of *Y. ruckeri* and *A. salmonicida*.

Although the fish immune system lacks the complexity of the immune system of higher vertebrates, it is possible to confirm past infections using methods that detect the presence of antibodies in fish serum. Techniques that have been used include neutralization (Dorson and Torchy 1979; Olesen and Jorgensen 1986; Hattenberger-Baudouy et al. 1989), fluorescent antibody (Jorgensen 1974; Ahne et al. 1986; Jorgensen et al. 1990; Olesen et al 1990), agglutination (Ward et al. 1985; Bruno 1987), precipitation (Kimura et al. 1978; Ellis 1985), and ELISA (Bortz et al. 1984; Cossarini-Dunier 1985; Kodama et al. 1985; Hamilton et al. 1987; Thuvander et al. 1987; Jorgensen et al. 1990; Olesen et al. 1990). These tests have been used for detecting fish antibodies resulting from active infection and vaccination. While caution should be used in interpreting ELISA data from fish (Thorburn and Jansson 1988), this method will find increasing use for evaluating the immune response of vaccinated fish and for confirming past exposure to specific pathogens.

The techniques of molecular biology have provided a number of powerful new tools for the detection of pathogens. After cloning part of a pathogen genome into a phage or plasmid vector (Sambrook et al. 1989), large amounts of DNA can be obtained that are homologous to the pathogen genome sequence and that will bind strongly and specifically to it. This complementary DNA (cDNA) can be labeled with either radioactivity or an enzyme and used as a "probe" for the direct detection of very small amounts of the genetic material of the pathogen. Synthetic cDNA can also be produced by automated chemical methods from an established sequence. Complementary DNA probes are now being evaluated as diagnostic reagents for *V. anguillarum* (Aoki et al. 1989), *Pasteurella piscicida* (Zhao and Aoki 1989), and IHNV (Deering et al. 1990). While the probes are still in a developmental stage, they promise a significant improvement in speed and sensitivity for detection and confirmation of many fish pathogens.

A new technique, known as the polymerase chain reaction (PCR; Saiki et al. 1985, 1988), uses two DNA primers and repeated rounds of polymerization to amplify a specific nucleic acid sequence to high levels. The amplified DNA can then be detected with a DNA probe (Erlich 1989; Innis et al. 1990). In addition to amplification of human gene sequences, early

applications of the method included detection of human pathogens with low copy numbers (Demler et al. 1988; Ou et al. 1988; Guatelli et al. 1989). Arakawa et al. (1990) used PCR to detect IHNV infection in cell cultures and rainbow trout. The method provided a rapid test for IHNV that approached cell culture in sensitivity.

Pathogen-free Water Supplies

Water systems are a common means for the introduction and spread of infectious diseases of aquatic animals. Water supplied by wells or springs is normally free of fish pathogens; however, surface water from rivers and lakes may contain large numbers of infectious agents from environmental or animal sources. Such open water supplies should not be used without treatment to make them pathogen free. In recent years, it has become practical to treat the large volumes of water used by modern salmon hatcheries. Usually, these systems make use of high efficiency sand filters, followed by final treatment with ultraviolet light, ozone, or chlorination-dechlorination (Wedemeyer et al. 1979).

Pathogen-free Diets

Modern salmon culture facilities rely heavily on artificial diets to maintain productivity (Halver 1972; Steffens 1989). The diet formulations often include fish products that require pasteurization to kill viral, bacterial, and protozoan pathogens (Herman 1970). In salmon hatcheries of the Columbia River in Oregon, a cycle of infection due to *Mycobacterium* sp. was eliminated by the pasteurization of the raw adult salmon viscera used in formulating the diet fed to juvenile fish. The role of nutritional factors in the progress of bacterial kidney disease has been studied (Wedemeyer and Ross 1973), but additional research is needed to define the interactions between various nutrients and disease resistance.

Hygiene and Sanitation

In addition to good animal husbandry, strict hygiene and sanitation measures should be standard practice in any aquaculture system (Herman 1970; Piper et al. 1982). Special care must be taken to avoid moving equipment (nets, brushes, etc.) between rearing units unless the articles have been adequately disinfected. Workers may spread infectious agents, and proper disinfection of hands and boots is required. Although it may be difficult to sanitize a pond or raceway during use, disinfection of these holding areas can be accomplished between uses. Hard-surfaced areas such as tanks and raceways may be disinfected with chemical compounds (chlorine, iodine, or quaternary ammonium compounds), while lime or dehydration in sunlight may be used on large earthen ponds (Herwig 1979; Piper et al. 1982). Because certain pathogens can be transmitted from adult to progeny as surface contaminants of fertilized eggs, disinfection of eyed eggs (Amend 1974) is effective at preventing the introduction of viruses or bacteria that are not physically inside the egg.

Disease Control Policy

To help control the important salmonid diseases that have a limited geographic distribution, restrictions have been placed on the transfer of fish and eggs unless they have been examined and certified to be free of specific pathogens (Rohovec 1983). Effective disease control policies should begin with an extensive survey to learn which diseases are present and in what areas they occur. Then effective laws can be written to protect stocks of fish from the importation of uncertified and potentially infected animals (Herman 1970). With increased international trade in fish and aquaculture products, additional regulations are needed to prevent the spread of important disease agents between countries. Only a few of the pathogens affecting cultured fishes are covered by present regulations, and many of these policies are out of date or lack satisfactory methods of enforcement. Because new pathogens are being discovered and new species of fish are being used in aquaculture, these policies require routine revision.

Nonspecific Immunity

Where fish pathogens are enzootic and pathogen-free water supplies cannot be provided, increases in host resistance may be beneficial. Natural disease resistance factors such as mucus, skin, interferon, and

natural killer cells will vary with age, species, and stock of fish. These factors are important but are affected adversely by stress (Pickering and Pottinger 1985; Wedemeyer et al. 1990). The resistance of fish to noninfectious disease is also reduced by stress (Wedemeyer and Goodyear 1984).

Vaccines Against Salmonid Fish Diseases

Immunization is the most effective method for controlling endemic diseases for which avoidance is not possible. In the last 10 years, vaccines have become available to protect fish against several important pathogens (Evelyn 1977; Rohovec et al. 1981; Ellis 1988). Currently, the only commercially licensed vaccines for use in salmonid aquaculture are preparations made from killed bacterial cultures (bacterins) of *V. anguillarum, V. ordalii, V. salmonicida, Y. ruckeri*, and *A. salmonicida*. These vaccines are generally effective and safe and can be delivered by waterborne exposure (Horne and Ellis 1988a). The success of fish vaccination has been made possible by the development of effective delivery systems for vaccines (Horne and Ellis 1988b). The delivery systems must be inexpensive and simple to be used commercially on a large scale. Fish vaccines can be delivered by injection, but this is a slow and costly method, useful only for valuable animals such as brood stock. For large numbers of fish, a hyperosmotic immunization method was developed that has now been replaced with a simple bath vaccination. Oral administration of vaccines has also been effective; however, the duration of immunity seems to be less than that of other methods.

Vaccines against fish diseases are now being developed using techniques of molecular biology. "Subunit' vaccines consist of only the portion of a pathogen (usually a single protein or a major antigenic domain) that will stimulate protective immunity. While they can be prepared by direct extraction from cultures of the pathogen, the most efficient method involves inserting all or part of the gene coding for the antigen into a bacterium, yeast, or virus that can express high levels of the protein as the cells multiply. Because no complete infectious units are present, the preparations are regarded as having a high level of safety and because the expression systems are efficient, the cost of producing the antigen is relatively low.

Portions of the genomes of IHNV, VHSV, and IPNV have been cloned and sequenced (Kurath et al. 1985; Duncan and Dobos 1986; Koener et al. 1987; Gilmore and Leong 1988; Bernard et al. 1990; Havarstein et al. 1990) and inserted into various expression systems able to synthesize viral protein antigens (Gilmore et al. 1988; Lawrence et al. 1989; Feyereisen-Koener and Leong 1990; Manning and Leong 1990). The antigens produced from these expression systems should be economical, safe, and relatively easy to license. While much work remains to be done, early results of vaccine trials are promising.

Attenuated viral vaccines can be delivered by simple waterborne exposure, and the weakened pathogen can be allowed to replicate in the animal, conferring an immunity that is often superior to that provided by killed vaccines. Because attenuated strains have the potential to revert to a virulent type or to replicate in unwanted ways, the testing required for this type of preparation is usually extensive, making the initial cost high.

Historically, attenuated viral vaccines were developed by serial passage of wild-type virus in cell cultures until the strain showed significant reduction in virulence, which required expensive testing. An attenuated IHNV strain was tested with encouraging results (Fryer et al. 1976), and de Kinkelin et al. (1980) described a thermoresistant variant of VHSV that could be used to protect rainbow trout (de Kinkelin and Bearzotti-Le Berre 1981). Recently, an attenuated strain of IHNV was developed by growing a wild-type virus in the presence of monoclonal antibodies against the virus, causing the selection of mutants with altered growth properties. Some of these mutants were reduced in virulence and were able to protect rainbow trout against IHNV infection (Roberti 1988).

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Habitat Consideration in the Restoration of Pacific Salmon

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Abstract. Salmonid habitats in the western United States have been degraded by logging, mining, pollution, road construction, gravel removal, bank stabilization (revetments, riprap), cattle grazing, dams (which eliminate habitat or kill migrating fish), inefficient or no screens at water diversions, and reduced stream flow. Restoring the productive capacity of the waters by methods that involve altering habitat in the stream often will be ineffective unless the life history of the species of interest is adequately known and considered. Effective solutions will be those that improve survival during or after the limiting period of density-dependent mortality. I describe some of the problems confronting managers from the western United States in their attempts to restore populations of anadromous salmonids where habitats have been degraded. The examples used concern chinook salmon (*Oncorhynchus tshawytsoha*) in the Sacramento, Klamath, and Columbia Rivers. In each example, the effectiveness of restoration efforts is compromised by a lack of knowledge of the factors that limit production of salmon.

Naturally reproducing (wild) populations of anadromous salmonids have declined in the western United States because of the release of hatchery-reared fish, excessive fishing, and habitat degradation. The causes of habitat degradation have included logging, mining, pollution, road construction, gravel removal from streams, bank stabilization (revetments, riprap), cattle grazing, dams (which eliminate habitat or kill migrating fish), inefficient or no screens at water diversions, and reduced streamflow.

More and more, the public expects that crops should be grown, timber harvested, minerals extracted, livestock managed, and municipal and industrial effluents treated in ways that do little or no damage to streams and lakes. Where fish habitat has been degraded by sediment from logging, road building, or other anthropogenic disturbances to terrestrial ecosystems, the best (long-term) solution is to promote recovery of the terrestrial system. Where dams or water diversions cause the loss of adult or juvenile fish (after the limiting period of density-dependent mortality), the best solution is to modify the structure or the operation of the structure to reduce the losses.

Sometimes the "best solutions" to habitat degradation problems are not acceptable, however, because costs are high or "quick fixes" are desired. Proposed solutions frequently entail increasing the amount of one type of habitat. Such solutions often will be ineffective unless they increase the carrying capacity for fish during or after the limiting period of density-dependent mortality. Often restoration efforts have proceeded without adequate knowledge of when this period occurs.

I describe some of the situations confronting managers in the western United States in their attempts to restore wild populations of anadromous salmonids where habitats have been degraded. The

examples used concern chinook salmon (*Oncorhynchus tshawytscha*) in the Columbia River system (Oregon, Washington, and Idaho) and in the Klamath and Sacramento Rivers of California (Fig. 1).

Spring Chinook Salmon in the Upper Columbia River

Chapman (1986) estimated that the Columbia River produced, on average, at least 500,000 adult spring chinook salmon per year between 1890 and 1895. Currently, production is about 185,000 adults, and many of these fish are from hatcheries. Dams block access to spawning and rearing areas, and habitat has been degraded by cattle grazing, logging, mining, and water withdrawals. A substantial part of the decline was caused by dams on the mainstems of the Columbia and Snake Rivers (Raymond 1988).

Mortality per project (a dam and reservoir) has been as high as 45%, and most fish from the upper Columbia River (above McNary Dam; Fig. 2) must pass between seven and nine mainstem dams when they migrate to sea as juveniles, and again when they return as adults to spawn. Currently, survival rates for downstream migrants are substantially higher than in earlier years because of reductions in supersaturation of dissolved atmospheric gases (mostly nitrogen) below dams, fingerling bypasses at dams (to prevent juveniles from passing through turbines), transportation of smolts around most of the dams, and releases of water from reservoirs to supplement river flows during the period that most smolts migrate downstream. Nevertheless, mortality is unlikely to be reduced below 12% per project, on average, in the near future.

The cumulative effect of the 12% or greater morality per project has reduced the survival of downstream migrants by more than 60% from pre-dam levels (Fig. 3). Consequently, managers are planning massive outplanting programs, wherein hatchery fish (fish reared for some portion of their life in a hatchery) will be released in streams to supplement natural production.

Outplanting results in a mixing of artificial and natural production systems. Problems can occur (Reisenbichler 1985) because of harvest in mixed-stock fisheries (McIntyre and Reisenbichler 1986), interbreeding of hatchery and wild fish (Chilcote et al. 1986; Reisenbichler and McIntyre 1986), and competition resulting from increased densities of juveniles in natural rearing areas (Nickelson et al. 1986). Competition is most directly related to habitat and is emphasized in this paper.

Managers must have knowledge of the limiting period of density-dependent mortality and of the stream's carrying capacity during that period (and perhaps for fish at other life history stages) if undue competition is to be avoided. If it is feasible to release hatchery fish after density-dependent mortality limits the abundance of naturally spawned juveniles, it may be possible to increase production from a stream beyond that possible with no outplanting. Exceeding the carrying capacity of a stream by releasing hatchery fish should be avoided because it will reduce the survival of both hatchery and wild fish, thereby reducing the cost effectiveness of the outplanting program and excessively altering the genetics of the wild population (Reisenbichler 1984). Only if the carrying capacity of the habitat is known can managers be sure that it is not exceeded by outplanting.

Spring chinook salmon in the upper Columbia River (herein defined as the area above McNary Dam) migrate to the ocean in spring, about 1 year after emerging from the gravel. Biologists generally have assumed that the low-flow period near the end of summer limits the production of juveniles; however, this assumption may be incorrect.

T.W. Hillman (personal commun., Don Chapman Consultants, Inc., McCall, Idaho) believed that the amount of habitat available to newly emergent fry limited the natural production of chinook salmon in the Wenatchee River, Washington. Hillman et al. (1987) found that winter habitat limited production of juvenile fish in other streams or stream reaches of the Columbia River system; however, the associated fish populations may not always be limited because fish may move to downstream areas that are too warm for salmonids during summer but become habitable (cooler) during fall, winter, and spring. Large numbers of juvenile salmonids leave tributary streams during fall (Bjorn 1971), presumably to overwinter in downstream areas.

The limiting period of density-dependent mortality remains unknown for most fish populations in the Columbia River system. One reason that questions about the carrying capacity of streams remain unanswered is the difficulty and expense of conducting studies in large streams.

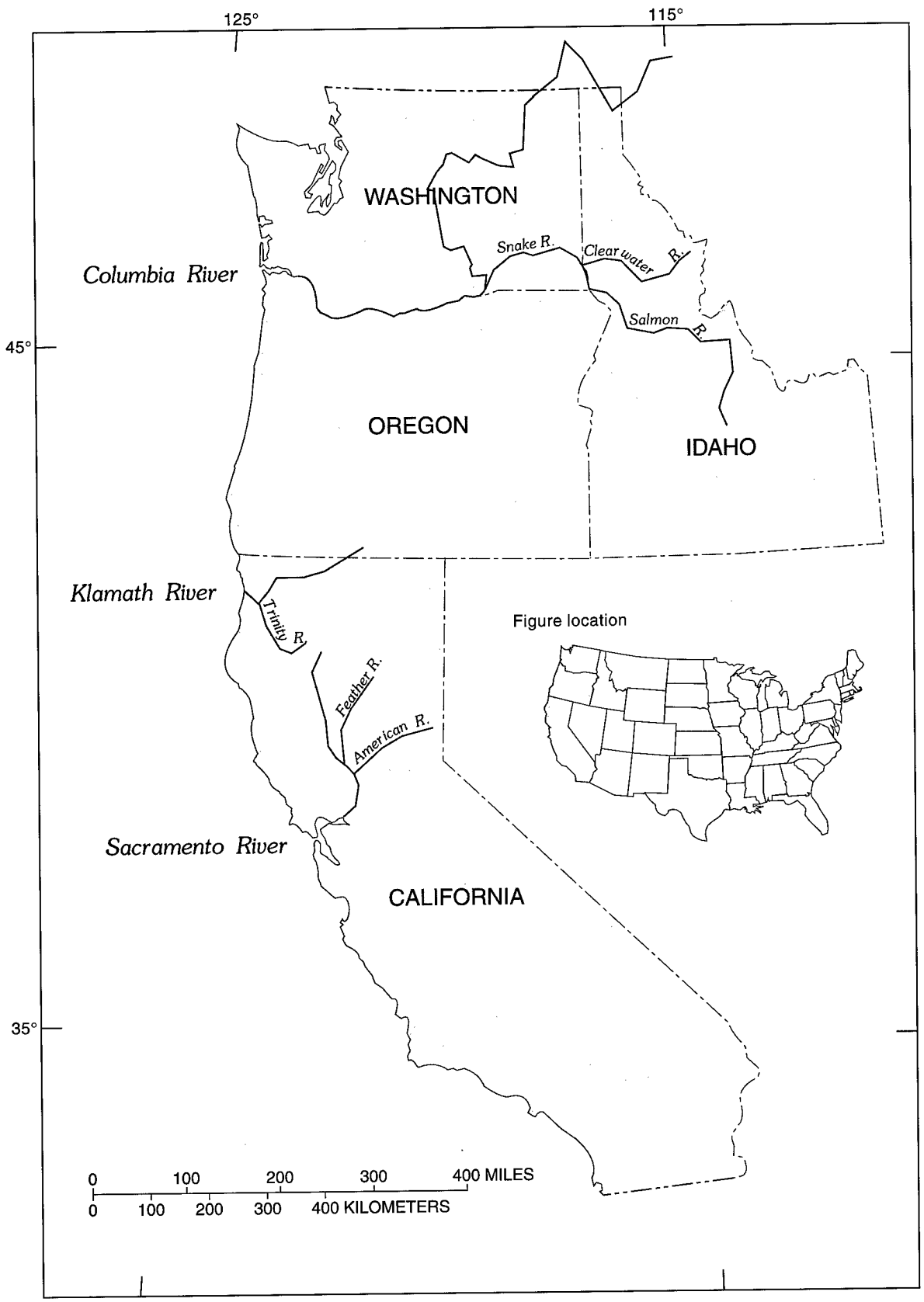

Figure 1. Columbia, Klamath, and Sacramento Rivers, western United States.

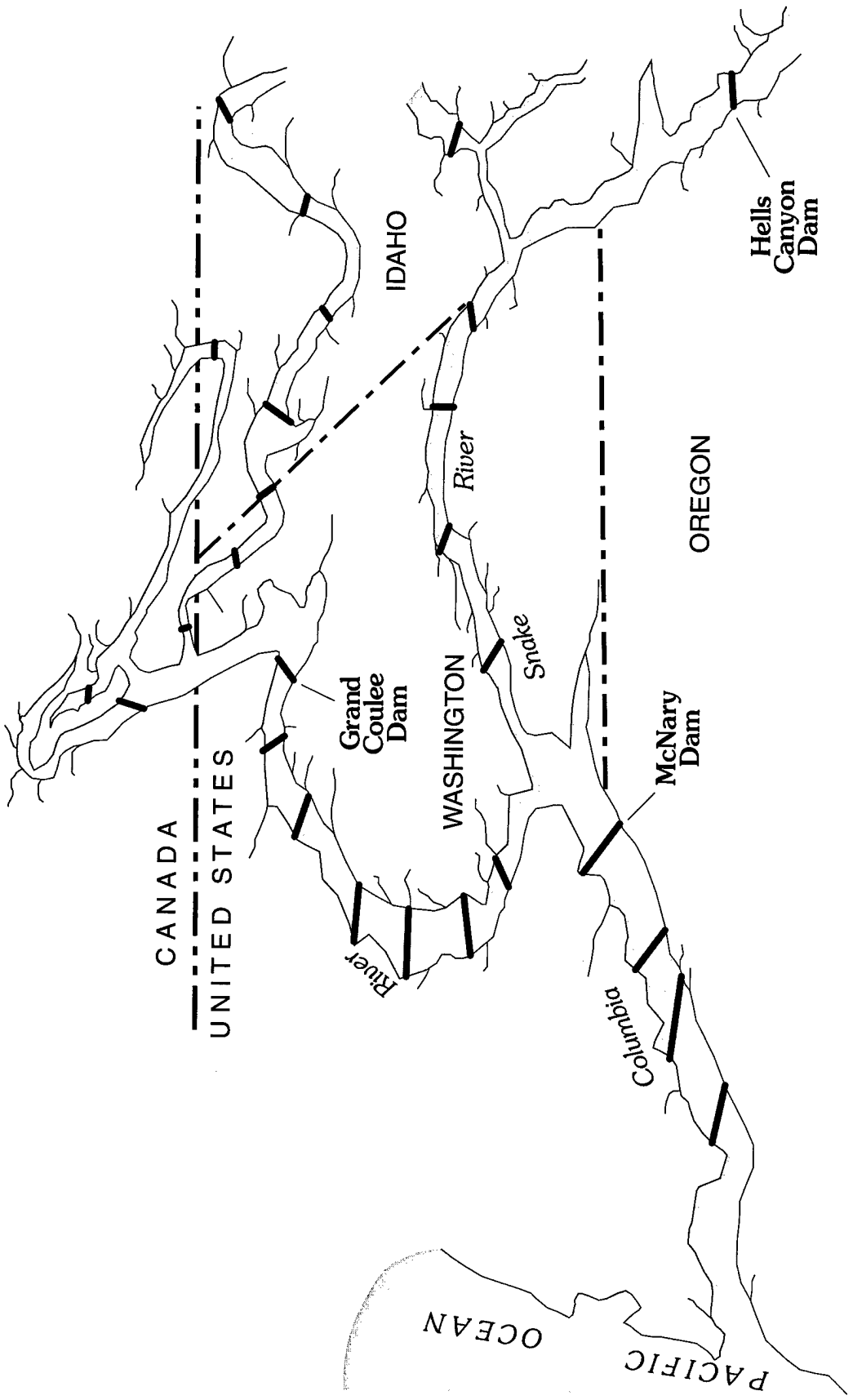

Figure 2. Dams on the Columbia and Snake Rivers. In this paper, the river above McNary Dam is called the upper Columbia River. Anadromous fish are blocked at Grand Coulee Dam, on the Columbia River, and Hells Canyon Dam on the Snake River.

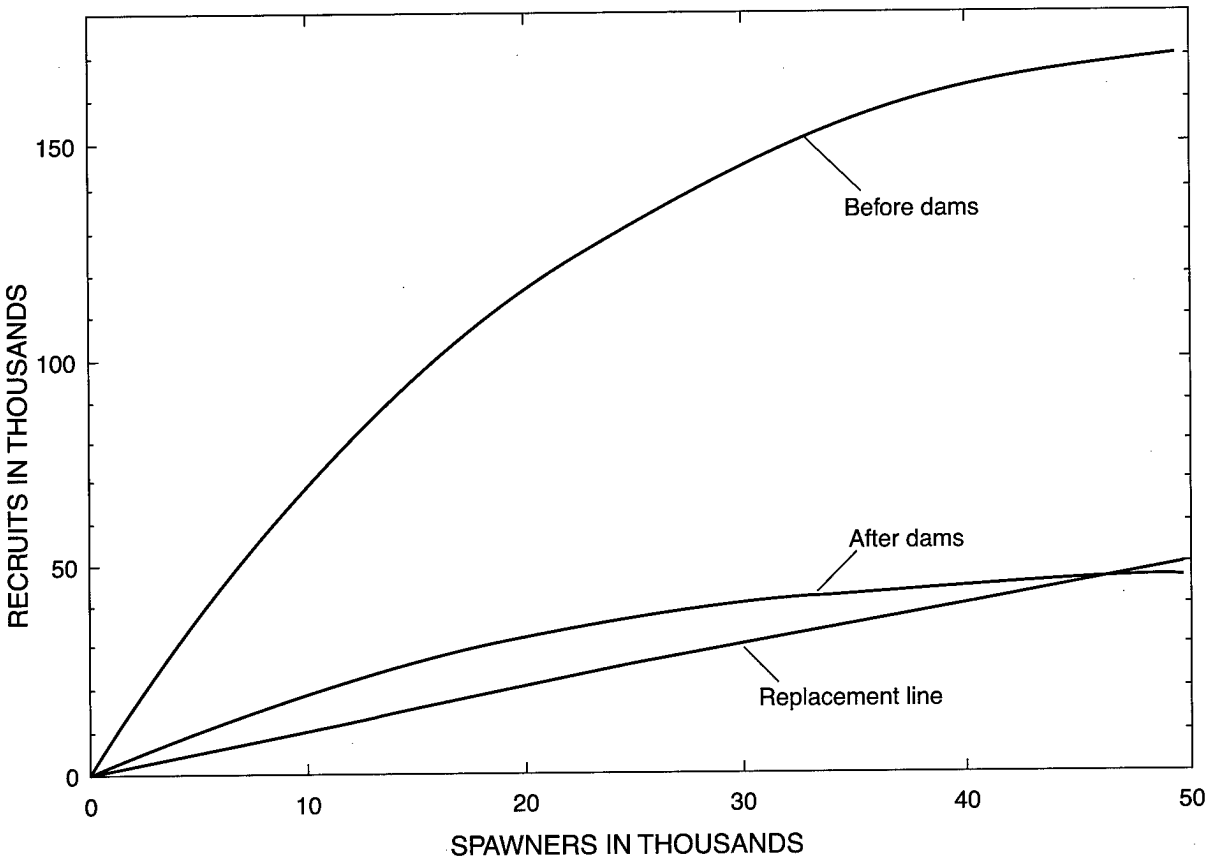

Figure 3. Spawner-recruit relations for spring chinook salmon in the Snake River before and after the eight dams were built between the spawning areas and the ocean.

Fall Chinook Salmon in the Klamath River

The number of fall chinook salmon returning to the Klamath River has declined. This decline probably is reflected by the decline in the Shasta River, one of the principal tributaries (Fig. 4). Causes of the decline of the Klamath River population include mining, logging, water withdrawals, and fishing.

Some managers would like to "improve" habitat in tributaries of the Klamath River to increase salmon production. Many of the juvenile fish leave the tributaries (excluding the Trinity River) shortly after emerging from the gravel (rather than as smolts), rear in the mainstem, and enter the ocean during their first spring, summer, or fall. Surveys of habitat in the tributaries indicate that spawning habitat is more plentiful than rearing habitat (personal communication, Jack West, U.S. Forest Service, Etna, California). Consequently, some managers have been eager to initiate projects that would increase the amount of rearing habitat. Such enthusiasm may be misdirected because the importance of the mainstem for rearing juvenile salmon is unknown. The rearing habitat in the Klamath River system (mainstem and tributaries) may be able to support far more juvenile salmon than can be produced in the available spawning areas.

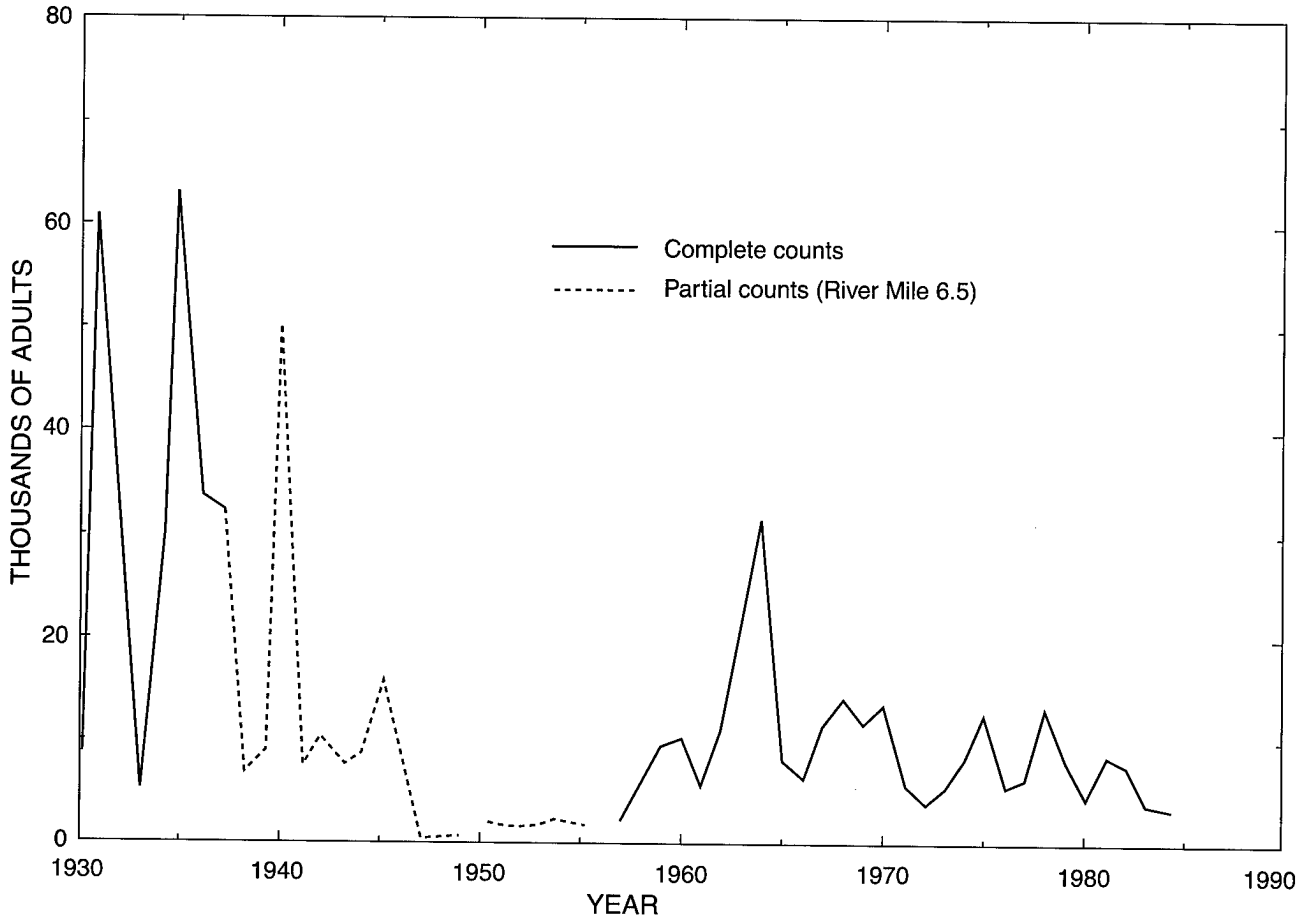

Figure 4. Number of fall chinook salmon returning to the Shasta River, tributary to the Klamath River. The dotted line indicates incomplete counts.

As in the Columbia River basin, the question of habitat limitation remains unanswered because of the difficulty and expense of conducting studies in large streams (e.g., the mainstems of the Klamath River). Biologists are attempting to use growth patterns of fish otoliths or scales to document the relative importance of mainstem and tributary rearing in the Klamath River system, thereby helping to define the question more thoroughly.

Fall Chinook Salmon in the Sacramento River

The numbers of fall chinook salmon returning to the upper Sacramento River (above the Feather River) have declined substantially since mid-century (Fig. 5). Causes of this decline include dams, water diversions, gravel removal, and fishing. The stabilization of banks with riprap (rock revetments) may have contributed to the decline. Most bank stabilization has occurred in the middle and lower reaches of the river, downstream from the spawning areas. The U.S. Army Corps of Engineers (the agency doing the stabilization) and the fisheries conservation agencies agree that riprap eliminates rearing habitat for juvenile chinook salmon. The Corps, however, has maintained that spawning habitat, not rearing habitat, limits the production of salmon in the river, so bank stabilization does not reduce the production of salmon.

Again, a lack of knowledge of the limiting period of density-dependent mortality and carrying capacity at different life-history stages limits the effectiveness of management, and again, the difficulty and expense of working in large rivers has been responsible for much of this lack. Also contributing to this lack of knowledge, though, is the complex life-history of juvenile salmon in the Sacramento River. For

example, juvenile fall chinook salmon enter the ocean in their first spring, only a few months after emerging from the gravel. In some years, most of the juveniles rear between river kilometer (rkm) 480 and rkm 260; in other years, many (but an unknown proportion) of the juveniles rear between rkm 260 and the ocean. Apparently, many juveniles gradually move downstream as they grow (termed "rearing migration"), rather than remaining in one area during most of their stay in fresh water.

Rearing migrations and interannual variations in distribution pose severe problems in designing studies to determine the degree of density-dependent effects at different life-history stages. Because of these difficulties, uncertainty about the relative amounts of spawning and rearing habitat in the future, and the potential of outplanting programs to seed the river to carrying capacity regardless of the amount of natural spawning, the wisest use of the limited money for research may be to learn how to stabilize banks with little or no loss of habitat.

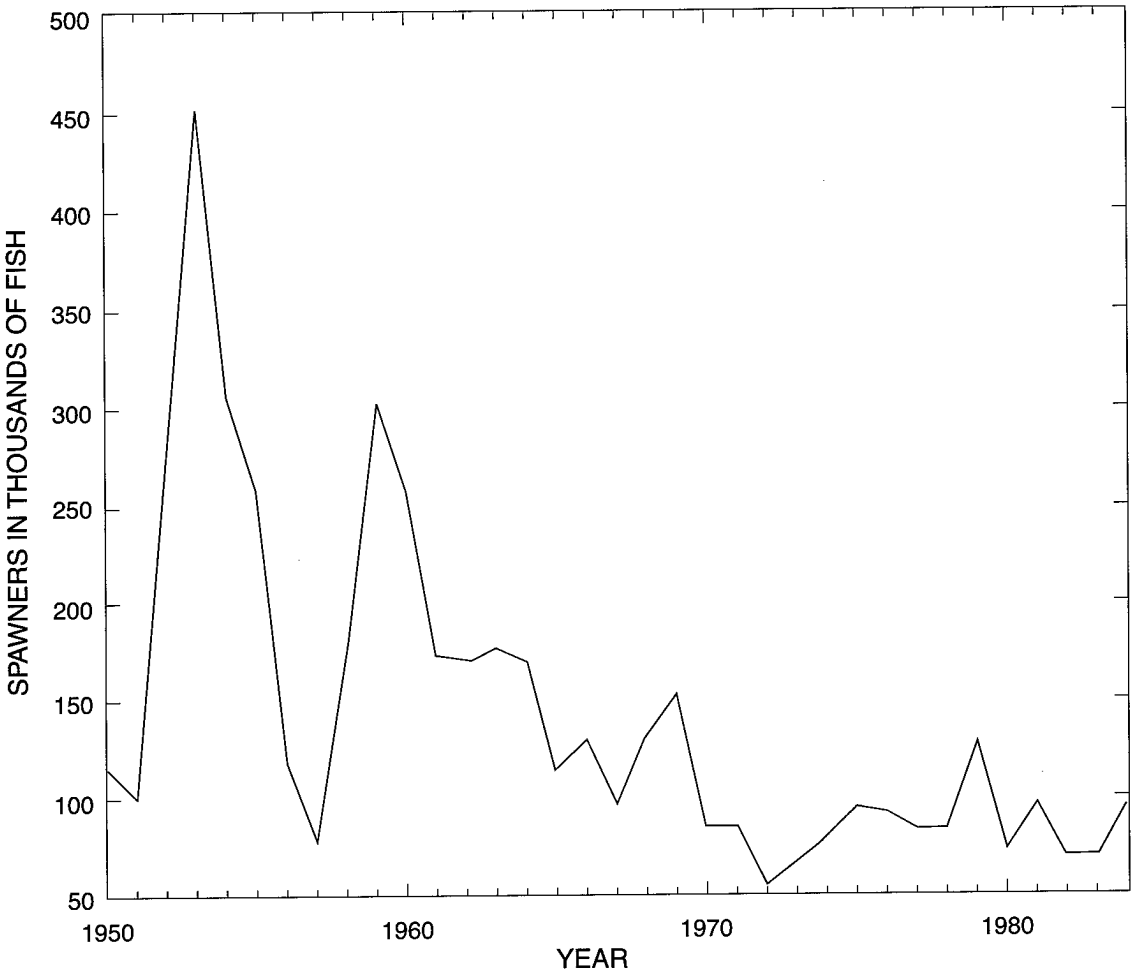

Figure 5. Number of fall chinook salmon spawning in the Sacramento River, California, upstream from the Feather River

Discussion

Our knowledge often is inadequate for selecting efficient techniques to restore natural production quickly. When knowledge is inadequate, managers should be cautious to avoid inadvertently damaging natural populations (e.g., by exceeding the carrying capacity of natural rearing areas with hatchery fish), improving or creating only one type of habitat (the type manipulated may not be the type that limits production), or condoning loss of any habitat favored by salmon. Outplanting should occur at modest levels until it is determined that greater levels will have little effect on wild fish. Where feasible, all types of habitat used by the fish (e.g., spawning and rearing habitat) should be improved or created unless biologists determine which type is limiting production. Alternatively, it may be prudent to manipulate nothing until the limiting habitat is known. Similarly, habitat should not be ceded to developers unless managers know that it does not and will not limit production.

Managers will continue to initiate enhancement and restoration projects without adequate knowledge of limiting factors. Some projects will proceed because the studies necessary to identify the limiting factors may require many years to complete, may cost nearly as much as the enhancement work itself, or may not be feasible. Nevertheless, it is important to increase our knowledge so that future projects will be based on more complete knowledge. Accordingly, the projects themselves should be considered as means to learn more about the limiting factors in streams. Rigorous evaluation should be an integral part of most projects, and special emphasis should be placed on studying phenomena that are common to other streams.

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Laws and Regulations for the Protection of Anadromous Fish Habitat in the United States

by

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Abstract. America's extensive and diverse inland, anadromous, and estuarine fishery resources are of enormous benefit to the Nation and its people. The nearly 60 million people who fish recreationally each year spend $30 billion in pursuit of this activity. Commercial fishing employs nearly 200,000 people in an industry that generates about $8.7 billion annually. Both figures would increase with improvements in fish populations. A variety of laws and treaties have been put in place in the United States and Canada to protect fishery habitat. Many of these laws seek to have the benefits of the resource considered when projects that would adversely affect fish stocks are undergoing environmental review.

America's extensive and adverse inland, anadromous and estuarine fishery resources are of enormous benefit to the Nation and its people. The nearly 60 million people who fish recreationally each year spend $30 billion in pursuit of this activity. Commercial fishing employs nearly 200,000 people in an industry which generates about $8.7 billion annually. Additional revenue would be generated with improvements in fish populations.

I review some of the most important pieces of legislation affecting the protection of fisheries and try to place them in the political context in which they were passed and how they are used today. A list of selected legislation concerning conservation of habitat is given in the Appendix. Some of the strongest laws and regulations used today in the United States to protect fishery habitat areas are not specific to that purpose; fisheries are usually included in the context of "fish and wildlife species." Often the wildlife aspects of these laws are more vigorously enforced.

Fisheries have been regulated since colonial days. The history of fisheries regulaton reflects changes in the way the U.S. society has viewed the environment in general. In colonial times the health of the economy was paramount. Today society views environmental health as an increasing priority.

Early legislation focused on the limitation of harvest to sustain a fishing industry. Restrictions were generally in the form of limits on total pounds that could be taken in any year. Later regulations restricted fishing by specification of gear type, seasonal limitations, size limitations and other methods of making fishermen less efficient. Stocks, however, continued to decline. In 1969, with the passage of the National Environmental Policy Act, the legislative tone changed from one of limiting take, to one of fostering broad-based resource planning and habitat protection. Some legislation, such as the Endangered Species Act (ESA) of 1973, is aimed at the protection of individual wildlife species once their populations are totally depleted. That legislation provides for the designation of habitat to be protected. The introduction to the act states that protection of the ecosystems which fish and wildlife depend is key to their survival.

One problem with comprehensive national fisheries legislation is the need to find methods to protect a variety of species that have the many and varied habitat requirements of fishes, from nursery

wetlands in riverine systems to pelagic harvest areas. One method to overcome this problem has been the use of interstate and international compacts to address regional fisheries problems.

The Canadian Government has passed legislation that specifically seeks to protect fishery habitats. However, the United States has yet to impose this type of habitat protection for fish species.

This leaves the United States Government in a position of enforcing habitat protection through the use of general environmental legislation or through evolving court interpretation of older pieces of law that survive today.

One of the earliest pieces of environmental legislation that affected fisheries was the Rivers and Harbors Act of 1888, which authorized the Secretary of the Army to construct fishways whenever federal river and harbor improvements obstructed the migration of anadromous fishes. The legislation did not contain provisions for funding this activity, so the discretionary action of providing fish passage was rarely pursued.

Additional authority was placed with the U.S. Army Corps of Engineers in 1899 when a revised Rivers and Harbors Act was passed that required federal permits for almost any construction in "navigable waters." The purpose of these permits was to protect interstate and international shipping through the exercise of review requirements over proposals to place structures in waterways or to build bridges or causeways. Despite the fact that this legislation was intended to protect shipping, not fishing, it provided means for the federal review of development projects in American waterways.

The Fish and Wildlife Coordination Act of 1958 follows the model of the Rivers and Harbors Act. It expanded the requirement for federal projects and those projects federally permitted in "waters of the United States" and adjacent wetlands to be reviewed specifically for possible impacts to wildlife.

Since 1899, federal courts have been used to adjudicate interpretations of the Rivers and Harbors Act and the Fish and Wildlife Coordination Act. The basic issue always is to determine the correct balance between the public benefits of maintaining an existing fishery and its associated industry or to allow the expansion of other commercial pursuits such as waterfront housing.

Court decisions have upheld the far-reaching implications of these laws by interpreting "navigable waters" to include any U.S. water with a link to interstate commerce. In turn, interstate commerce has been broadly interpreted to apply to almost any use of waterways, from canoeing to bird watching. Other court cases have held that adjacent wetland areas are part of the navigable waters system.

Through the use of these court decisions the federal review responsibility has extended into the spawning and nursery areas of anadromous fish. However, this review authority does not contain a prohibition against the construction of projects that will adversely affect fisheries.

The lack of direct funding, of a requirement that fish passage be provided (despite the authority to provide such passage), and of a prohibition against projects that damage the fishery has led to the construction of many harmful projects. One example is a series of permanent dams on the Susquehanna River. These dams have blocked the passage of American shad (*Alosa sapidissima*), American eels (*Anguilla rostrata*), striped bass (*Morone saxatilis*), alewife (*Alosa pseudoharengus*), and blueback herring (*A. aestivalis*).

Shad landings in the Susquehanna drainage peaked in the 1890's. By the 1890's the construction of the four hydroelectric dams was complete and commercial landings were 2% of the previous total. The adverse effects on the fishery were considered secondary to the benefits of energy generation for a growing population. This type of analysis is called a "public interest review."

The Clean Water Act is an example of an act that establishes a permitting program actually aimed at the protection of habitat. The program is administered by the Corps of Engineers. As part of the permitting process the Corps must seek the advice of the Fish and Wildlife Service and the fish and game agencies of the affected states. The Corps must also abide by the guidelines established by the Environmental Protection Agency.

These guidelines are known as the 404(b)(1) guidelines, after the section of the act that describes them. The Corps reviews the advice of the commenting agencies and makes a public interest determination. A permit is not to be granted if it is contrary to the public's interest. Despite the stated goal of "restoring and maintaining the chemical, physical, and biological integrity of the Nation's waters." Clean Water Act permits are often seen by individual legisla-

tors as obstructing economic development of private enterprises within their state or district.

Not all of this is a cloudy picture. Based on these legislative tools and the subsequent creation of the Federal Energy Regulatory Commission, it became possible for the activities of those four dams on the Susquehanna River to be reviewed. In 1985, 59 years after its completion, an out-of-court settlement resulting from the relicensing procedure for the Conowingo Dam on the Susquehanna River forced the provision of fish passage. Plans, construction, and testing of these retrofits are ongoing.

At the time the Fish and Wildlife Coordination Act was passed in the 1950's, hunting and fishing were considered venerable traditions or character-building hobbies–synonymous with the American way of life. Despite declining fish populations, few Americans really thought about a United States that would not have sufficient habitat to allow for a healthy commercial and sport fishery.

This attitude is reflected in the way the Coordination Act was written. Forward-looking legislators believed it was important for biologists to give wildlife information to project engineers, but they did not make it incumbent on those engineers to modify the design of projects to provide such basics as fish passage and protection of spawning areas. Hence, environmentally sound construction and operation of projects becomes a matter of dispute between federal agencies. If there is a public interest group, that pursues the issue, these disputes become a matter for the courts to adjudicate.

Similar fish passage stories are being played out all over the New England states as these areas were settled early in the history of the United States. Some of the western states have different problems. As they say in California, "Whiskey is for drinking; water is for fighting over." The uses and abuses of water on the west coast, a part of the United States that has substantial rainfall in some areas and deserts in other areas, leads to a special set of problems for anadromous species. For instance, although northern California has rainfall of over 50 inches a year, much of it is used for agriculture or diverted to the southern desert areas of the state for agriculture and municipal purposes.

These uses have led to water contamination and low flows in areas that once supported salmonids. Today, for instance, the California winter chinook salmon runs are so reduced that protection of this population under the Emergency Striped Bass Act has been invoked by the National Marine Fisheries Service.

The Emergency Striped Bass Act (passed in 1973) is a potent piece of legislation which provides protection for individuals of a species whose population numbers are declining at a rate at which, without protective intervention, they would probably become extinct. The law also protects habitat listed as "critical" to the continued existence of the species.

The concept of protected habitat is critical to the success of recovering migratory species. Without such protection the law only forbids the killing, harming, and harassment of individuals. The connection between the harming and harassment of individual animals and the fact that the species as a whole is harmed by the loss of habitat has been difficult to make once a species has migrated out of streams into international waters.

The passage of the Emergency Striped Bass Act followed an even more broad piece of legislation affecting the protection of habitat areas for all wildlife, the National Environmental Policy Act of 1969, known today as NEPA.

In 1969, two things were happening in American, indeed in global, society, that reflected directly on how NEPA was written. The first issue was a growing alarm that human health was being threatened by myriad problems; including nuclear energy, toxic waste, world population growth, and climatic changes. There was a growing ecological movement, and a humane movement that can be seen today in organizations seeking reform in animal research and environmental policies, groups such as Greenpeace and People for the Ethical Treatment of Animals.

The second issue in U.S. politics was a sense that government had grown too large. There was a feeling that civil servants ought to be more responsive to local problems. The Federal Government underwent reform in the late 1960's and early 1970's, and NEPA was the cornerstone of those changes, not just for environmental matters but in all management touched by the federal system.

NEPA is procedural in nature, it requires disclosure of impacts but it does not mandate a particular course of action. Although adjudication of differences between agencies is vested in the President's Council on Environmental Quality, in the final analysis it is

enforced not by a federal agency, not by Congress, but by litigation by citizens.

NEPA requires that all projects the Federal Government may propose, from building jails in Manhattan, New York, to building dams on the Columbia River in Washington State, be studied and the adverse effects of those projects be made public. Public hearings are required if requested, and documents must be made available to the public in accessible locations at no cost. While the litigation provisions of NEPA insures that government decisions can be challenged, this method is not a panacea. Few individuals have the funds to challenge the U.S. Government's procedures. But private environmental groups with large memberships, such as the Sierra Club, have formed legal defense funds that collect sufficient donations from the public to bring suit on a fairly regular basis.

Another act passed in 1976, "The Fishery Conservation and Management Act," also employs active citizen involvement in management of "public trust" resources. This act is specific to fisheries and embraces the concept of regulating fishermen and protecting habitat as the means to insure the continued existence of fish populations sufficient to support a commercial and recreational fishery.

This act provided for U.S. authority over fisheries, including foreign fishing fleets, from 3 to 200 miles from the U.S. shore. Protection of anadromous fish produced in U.S. rivers is one of the objectives stated in the act. The act also provided for the establishment of eight regional fishery management councils: New England, Mid-Atlantic, South Atlantic, Caribbean, Gulf of Mexico, Pacific, North Pacific, and Western Pacific.

Membership in the councils includes federal agencies such as the National Marine Fisheries Service (NMFS) and the Fish and Wildlife Service, and other federal representatives with an interest in fisheries such as the U.S. Coast Guard and the State Department. All of the other council members are selected from lists provided by the governors of affected states. To be eligible an individual must be knowledgeable or experienced with regard to the management, conservation, or recreational or commercial harvest of the fishery resources of the geographical area concerned.

The councils prepare fishery management plans for species that require such treatment. The plans include restrictions on harvest and conservation of areas where habitat protection is recommended. In addition to developing the management plans the councils have the responsibility to comment on any action that the government proposes to take and on private projects the government may permit. Permitting agencies must respond to the fishery management councils within 45 days to detail how they will implement the council's recommendations.

Again, enforcement of the act is by litigation by citizens. In this case, it is a particularly potent aspect of the law because the public members of councils, those chosen from lists provided by the governors, are not considered federal employees. Thus individual council members may bring suit against a federal agency that ignores council recommendations.

Interstate and international compacts are another method of regulating the habitat of fisheries in the United States. An example of these mechanisms is the Pacific Salmon Commission. The commission was established in 1985 by a treaty signed between Canada and the United States. Each country provides four commissioners and four alternates. Three regional panels—northern, southern, and Fraser River—provide technical information and regulatory advice to the commission. The panels are bilateral and analyze information from each country on habitat-enhancement projects and projected annual harvest of chinook (*Oncorhynchus tshawtscha*), chum (*O. keta*), coho (*O. kisutch*), sockeye (*O. nerka*), and pink (*O. gorbuscha*) salmon.

The treaty was considered necessary to encourage continued habitat improvements without the fear that the additional salmon produced would be fished out by the neighboring country. Because commercial and recreational fishing for salmon constitutes a considerable industry in both countries, the treaty was seen as a method to preserve jobs and secondary businesses, allow for the continued subsistence of north Pacific native people and preserve harmony between the two governments.

Two areas of proposed legislation that will greatly affect conservation of fisheries are seafood inspection and the potential for designation of nationally significant fishery conservation areas. The latter would specifically authorize the federal acquisition of areas important in the life cycle of specific fish species. Although there is legislation that allows the Federal Government to acquire wildlife habitat now, none of that legislation is specific to fisheries conservation.

The idea of food inspection is well established for agricultural producers; however, there has never been a system established for fish caught in the open oceans to be tested for parasites or contaminants prior to entering the market place. Currently, there are over 15 different bills pending in the U.S. Congress on this subject.

This legislation is controversial, as the potential for standards in fish handling and limits on biological contaminants in fish flesh may be considered additional burdens to the economically strapped fishing industry. Consider for a moment that a several-hundred-pound swordfish may bring $10,000 in today's marketplace. Fishermen who are told at dockside that their catch is too contaminated for sale surely will feel that they have become the victims of environmental pollution. This type of legislation may emphasize the need to restrict the entrance of contaminants into the open ocean.

As you can see from these examples, domestic U.S. legislation plays a part in the vision of global conservation. There appears to be a trend in the United States toward the protection of habitat while continuing the tradition of regulating harvest. Experts in the Fish and Wildlife Service estimate that 90% of wetlands in the United States have already been destroyed through development, and many salmon spawning areas have been blocked by dams or destroyed through sedimentation.

The challenge is to find the mixture of legislation and public understanding that will lead to sufficient habitat protection, which in turn will produce a sustained increase in fish population numbers.

Appendix

Selected Legislation Concerning Conservation of Habitat for Anadromous Fishes.

Land Acquisition

- Administration of National Wildlife Refuge System (16 U.S.C. 666dd–668jj) was established to consolidate authorities relating to the various categories of areas administered by the Secretary of the Interior for the conservation of fish and wildlife, including those species threatened with extinction, wildlife ranges, game ranges, wildlife management areas, and waterfowl production areas.
- Recreational Use of Fish and Wildlife Areas Administered by the Secretary of the Interior (16 U.S.C. 460k–460k–4) provides for the acquisition of lands associated with or adjacent to refuges for incidental fish and wildlife recreation.
- Emergency Wetlands Resources Act (P.L. 99–645) acknowledges the values of wetlands with regard to fish and wildlife, cultural history, groundwater recharge and discharge, flood desynchronization, and other values and authorizes certain acquisition through the Land and Water Conservation Fund.

Management and Conservation of Fisheries

- Preservation of Fishery Resources Act (16 U.S.C. 755–7601) as amended establishes national fish hatcheries for the artificial propagation of selected species and for projects in the Columbia River basin. It also provides a cost-sharing program with the states for projects aimed at anadromous fishery conservation, and to encourage commercial exploitation of marine species.
- Fisheries Conservation and Management Act (P.L. 94–265) establishes fishery management councils that are responsible for developing management plans for species of fish found within 200 miles of the United States coast. Most councils have habitat policies that encourage the conservation of spawning, nursery, and staging areas. Councils also may review proposed government activities or activities that require federal permits for effects on fishery resources.
- Fish and Wildlife Coordination Act (16 U.S.C. 661–667e) authorizes the federal agencies to seek the recommendations of the Fish and Wildlife Service and the appropriate state fish and game agency with regard to mitigation and possible enhancement opportunities of federal water projects.
- Clean Water Act (33 U.S.C. 1251–1376) extends the authority of the Fish and Wildlife Coordination Act to cover federally permitted activities described in Section 404.
- Endangered Species Act (16 U.S.C. 1531–1543) requires the designation of habitat as "critical" for the continued existence of listed species of plants

and animals including fish. A requirement for Section 7 consultation (a formal analysis by the Fish and Wildlife Service and the action agency) exists if critical habitat is to be adversely modified.

- Emergency Striped Bass Act (Section 7 of the Anadromous Fish Conservation Act, 16 U.S.C. 757g) provides funds for research on the causes of the decline of this recreational and commercial species, especially in the Chesapeake Bay.
- Compacts established the Atlantic States Marine Fisheries Commission, the Gulf States Marine Fisheries Commission, and the Pacific Marine Fisheries Commission, which are mandated to promote the better utilization of the marine, anadromous, and shellfish resources of the coasts and to develop a joint program to protect and prevent the physical waste of such resources.

Pacific Salmon Enhancement: New Opportunities

by

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The overall harvest of salmon in the North Pacific amounts to 600–700 thousand metric tons. In addition to the naturally reproduced fish, 5 billion juvenile pink, chum, coho, and chinook salmon are released in the North Pacific by the United States, Japan, Canada, and the Soviet Union. Some researchers are concerned that the capacity of this region for feeding salmon is close to its limit. However, in the last 10 years catches have actually increased.

Japan releases about 2 billion large-sized juvenile chum salmon annually for feeding in the North Pacific, providing a return of 40–50 million fish a year during the past 10 years. This number equates to 130–150 thousand metric tons, which is five times higher than the historical maximum catch of Japanese chum.

During the same period the abundance of sockeye salmon became considerably higher. The catch of sockeye of American origin went up by five times since 1975. The abundance of West Alaska sockeye grew to a particularly high level. The average catch for the past 10 years amounted to 80 thousand metric tons a year. The historical maximum of sockeye abundance in Alaska has been achieved and exceeded in contrast to the abundance of Asian (Kamchatka) sockeye, which remained low, providing an average catch of 5 to 7 thousand metric tons a year, including the Japanese catch (Forrester 1987).

The feeding areas of sockeye salmon of American and Asian origin overlap considerably (Fig. 1). The high seas regions of the Kamchatka and West Alaska sockeye have a particularly broad coincidence. The areas of these regions is about equal, and their capacities for feeding salmon are of the same order of magnitude. However, the production of sockeye salmon in the American feeding area is about 5 to 10 times higher. Hence, the food resources of the high seas feeding area of Asian sockeye may be assumed to be underutilized. This feeding area could provide much more sockeye to the Asian continent, especially to Kamchatka, if more sockeye smolts were released for feeding.

Can Sockeye Be As Profitable As Japanese Chum If Used For Ranching?

One of the most remarkable properties of sockeye is the high survival rate at sea. Figure 2 shows the dependence between the size of smolt and survival to fishing size in the ocean for the past 20 years (Koenings and Burkett 1987). The return of adult salmon from 2-g smolts is 5%, from 5-g smolts 7% to 15%, and from 10-g smolts 20% to 50%, which are very high levels.

We can compare these levels with the weight-return curves for other species of salmon (Fig 3). The ratio between the weight of smolt released and adult fish returned determines the efficiency and profitability of salmon ranching. For example, zero profit with regard to Atlantic salmon (i.e., profit expenditures = 1) is achieved at the 8% to 10% return from smolts of no less than 40 g. For coho, the size of return should not be less than 4% to 6%, the weight of smolts released no less than 10 to 25 g.

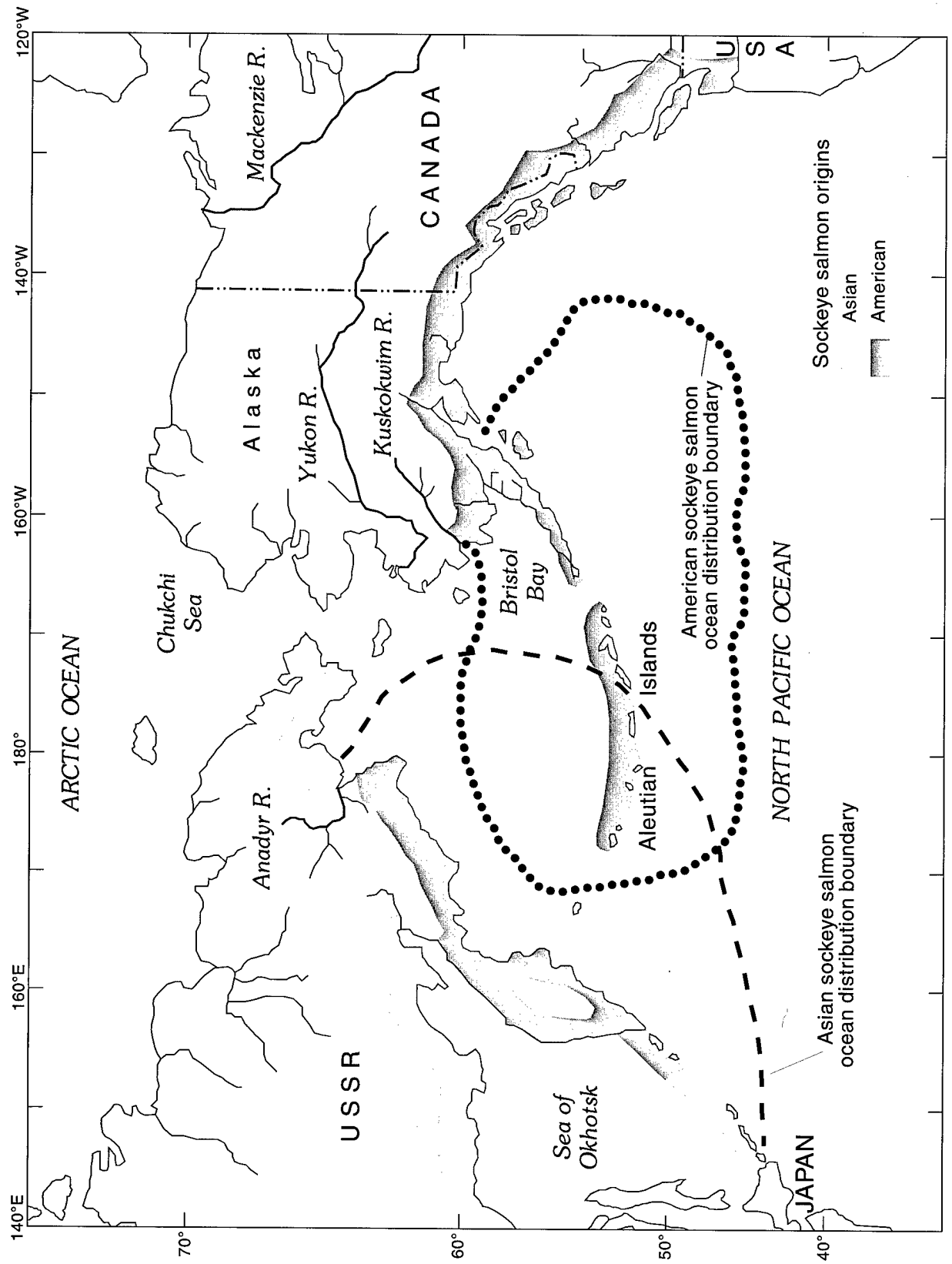

Figure 1. Ocean distribution of the sockeye salmon of Asia and American (western Alaska) origin.

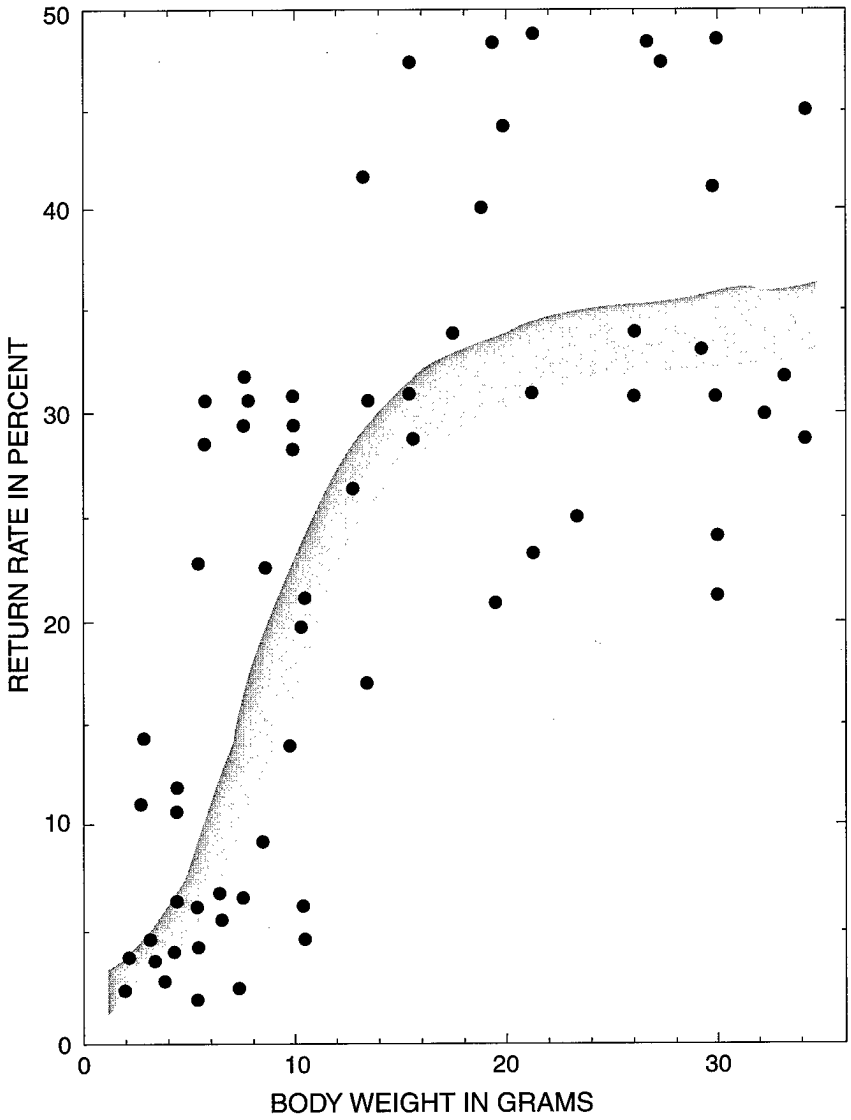

Figure 2. Ocean survival of the sockeye salmon smolts as a function of body weight (modified from Koenings and Burkett 1987).

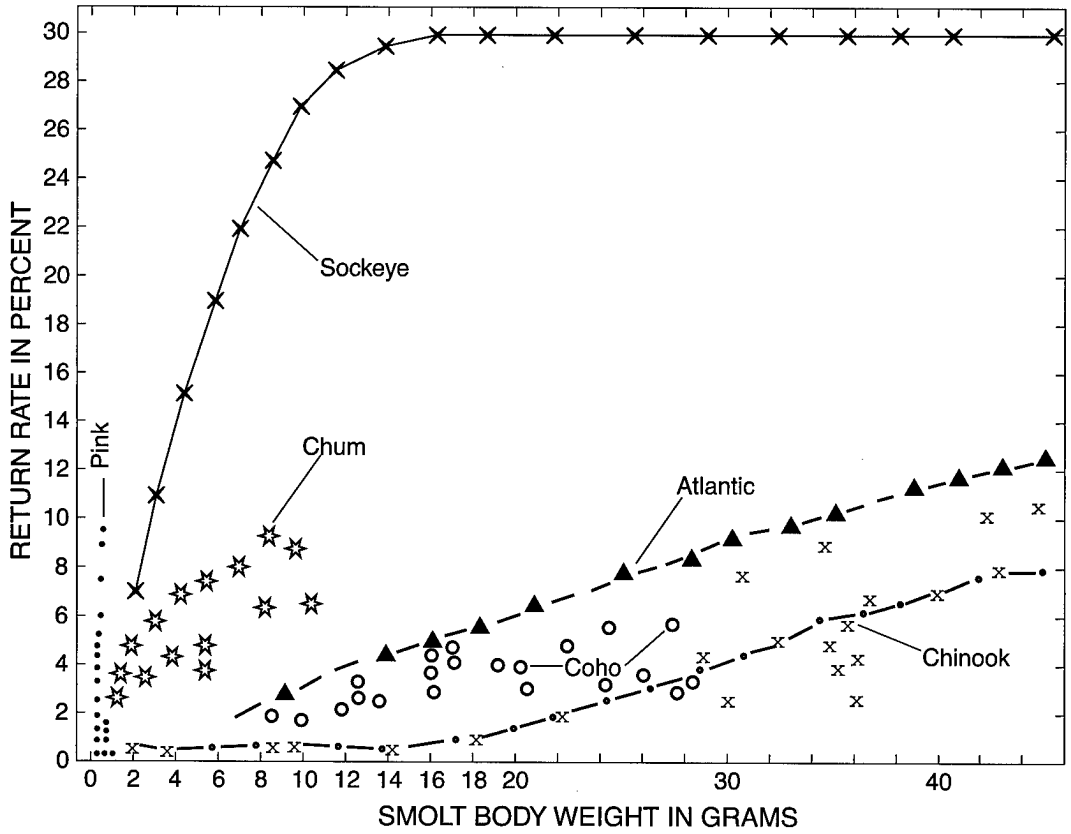

Figure 3. Comparative return rate as a function of smolt weight of different salmon species.

Similar indices were obtained for chinook. The highest efficiency is attained in ranching of chum; with the fishing return of 2% to 3% and the weight of smolt of about 1 g, the profit-expenditure ratio is 10 to 15, for example, $1 spent yields a $10 to $15 profit.

The efficiency of ranching chum salmon is high because the cost of rearing a small smolt is low. The rearing cost for juvenile chum is only 6% of the cost of catch of the returning fish (Billard 1988).

The size-return curve for sockeye differs considerably from the curves for other salmon. The fishing return from 2-g sockeye smolts is about 5%, while the ratio between the profit and expenditures may be about 15. The return is 15% for 5-g smolts and 20% to 50% for 10-g smolts. Accurate evaluation of efficiency is difficult, but the market price of sockeye is 15 times higher than that of chum, and the efficiency may be expected to be considerably higher. In other words, ranching of sockeye becomes very profitable under one condition: One must obtain sockeye smolts during one season.

Is It Possible?

Recent information indicates that some sockeye populations have underyearling smolts. Sockeye underyearling smolts of less than 1 g in the upper reaches of the Kamchatka River were described by Bugaev (1977). Similar sockeye smolts migrating to the sea soon after hatching were found in the Stikin River by Wood et al (1987), who identified three kinds of smolts: "sea smolts" weighing under 1 g, which migrate in the year of birth; "river smolts," which migrate at age 1; and "lake smolts," which spend 1 year or more in the lake.

According to Birtwell et al. (1987), some of the smolts migrate to sea in spring at the age of 1 year (65 to 75 mm long, 2 to 3 g). Smolts-of-the-year weighing less than 1 g migrate simultaneously. The latter do not go out to sea but grow in the estuary, leaving for the ocean in early autumn upon reaching about 2 g.

Koenings and Burkett (1987) found that in the case of most lake populations of Alaskan and Canadian sockeye, juveniles smoltify and migrate to the ocean at age 1, the minimum size and weight being 60 mm and 2 g. Those juveniles that do not reach the

critical size do not smoltify and remain in the lake for another year.

The ability of some sockeye populations, especially river ones, to produce underyearling smolts is one of the most remarkable characteristics of this species. If this ability is genetic, the identification of such populations could make the sockeye one of the most profitable species for ranching. However, despite indications of the existence of underyearling smolts, this possibility has not been proven experimentally.

We assessed the smoltification dynamics under accelerated rearing of one of the Kamchatkan Lake sockeye populations. Sockeye eggs of Kuril Lake were incubated at 6 to 7°C, and juveniles were reared at 7 to 9°C. Growth dynamics are shown in Fig. 4. Smoltification was assessed, using a seawater test of 30 ppt, by the level of osmolality of blood plasma of juveniles 24 h after a direct transfer from freshwater to seawater (Clarke and Blackburn 1977). The first signs of smoltification appear in the young at the weight of 2.4 g. Osmoregulation capacity in seawater grows rapidly; after 8 days it reaches the level characteristic for smolts: Plasma osmolality after 1 day in seawater does not exceed 340 m0sm/1 and does not differ significantly from the freshwater controls.

During the 8 ensuing days, the juveniles rapidly lose their capacity to adapt in seawater. The duration of the "smoltification window" is only about 16 days. This factor is probably explained by the relatively high temperature in rearing of juvenile sockeye salmon, though the temperature of 9°C is considerably below the optimum temperature of 15°C (Brett et al. 1969).

Figure 4 shows average weights of smolts. Of special interest, however, is the minimum weight of smolts in accelerated rearing. A special experiment was conducted to rear 200 sockeye fingerlings having the initial standard weight of 0.8 g. As the rearing went on, the extent of juvenile smoltification was assessed, as mentioned previously. As Fig. 5 shows, juveniles are unable to osmoregulate in seawater before reaching 1.8 to 2.2 g; the boundary weight is about 2 g.

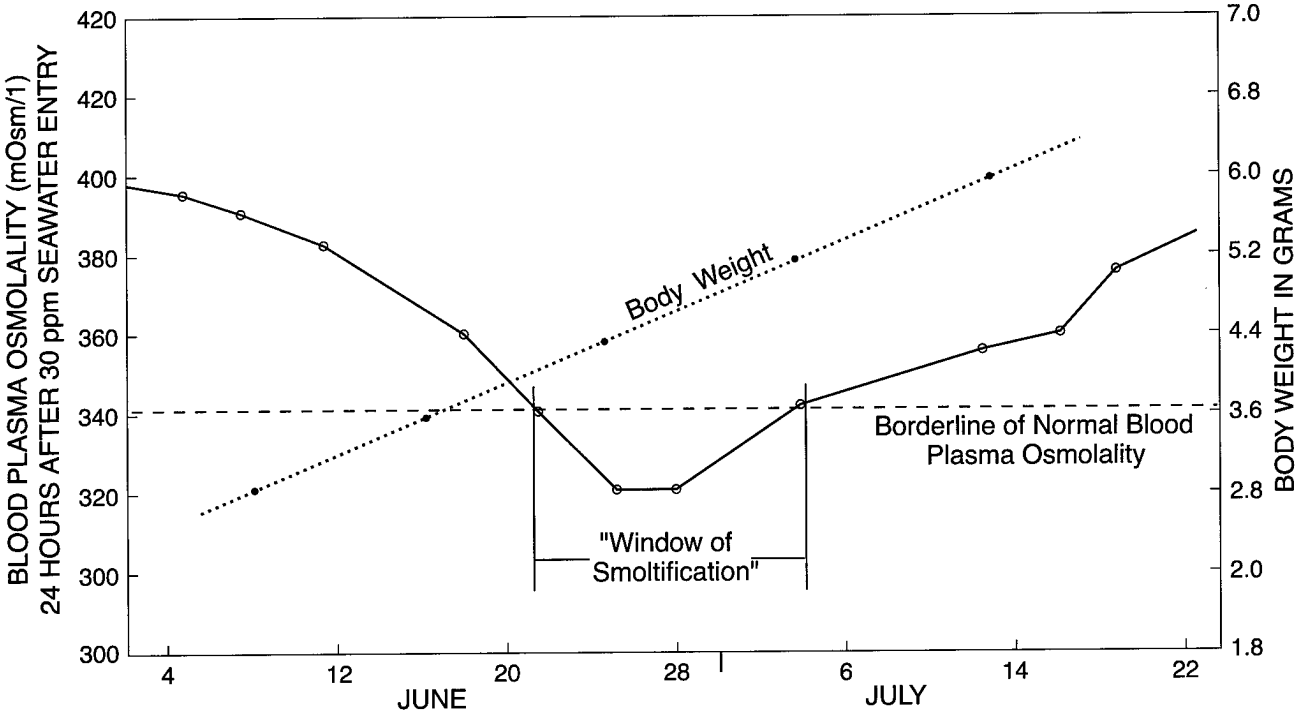

Figure 4. Results of sea challenge test in zero-age sockeye salmon juveniles as a function of calendar time.

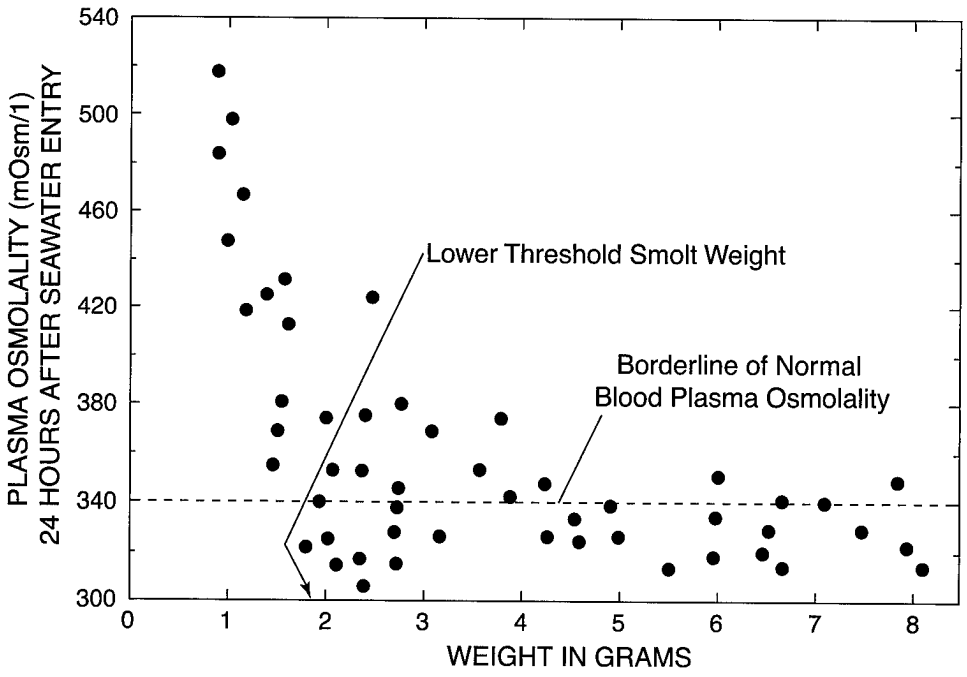

Figure 5. Smoltification of sockeye salmon juveniles, with growth and assessment of the lowest threshold weight of the sockeye smolts.

We think that the signal to smoltify comes when sockeye juveniles reach the minimum of 2 g while the photoperiod is increasing. This hypothesis agrees well with the data of Koenings and Burkett (1987), who showed that the lower boundary weight of smolts is 2 g. In natural conditions this growth requires 1 year, whereas under accelerated rearing at 7 to 10°C it takes 4 to 5 months.

Smoltification is governed by the achievement of the lower boundary size by the juveniles rather than by their age.

Conclusion

A potential surplus food resource is available in the North Pacific that could increase the abundance of salmon. Releasing large numbers of sockeye smolts into the ocean is a prospective way to enhance the Asian stock of this species. Under accelerated rearing mass smoltification occurs when underyearling juveniles reach a minimal weight of 2 g. Sockeye underyearlings can be obtained as quality smolts of 5 to 10 g in 4 to 5 months. The average return rate from such smolts is 15% to 40%, which indicates that sockeye ranching can be successful. Effective ranching requires testing of smoltification under accelerated rearing.

The potential early smoltification, high survival rate in the ocean, and a very pronounced homing effect make the sockeye a promising species for ranching not only within its original range but also potentially in the Atlantic Ocean.

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Organization, Operations, and Responsibilities of the United States Fish and Wildlife Service

by

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Federal stewardship for the United States' diverse and valuable fishery resources dates from the formulation of the U.S. Fish and Fisheries Commission in 1871, in response to concerns about the decline of supplies of domestic foodfish. The Commission was renamed the U.S. Bureau of Fisheries in 1903, transferred under the Department of the Interior in 1939, and renamed the U.S. Fish and Wildlife Service (Service) in 1974.

Over the subsequent 119 years, federal fishery resource involvement and responsibilities have grown, diversified, and undergone major organizational changes. Many factors were involved in these changes, but three have been central in shaping federal fishery resource responsibilities as they stand today: (1) a broad-based public awareness of the importance of fishery resources, especially as a source of recreation and low-cost food; (2) a recognition that fishery resources are finite and the consequences of their unregulated use, as well as the continued degradation and destruction of fishery habitat; and (3) an identified need for comprehensive and better coordinated management of fishery resources.

The Service, through its Fisheries Activity, is responsible for most federal inland fishery management activities and shares management responsibilities for anadromous species with the National Marine Fisheries Service. The Service does not have exclusive authority to regulate any inland fish species or fishery. The Service serves as a catalyst to ensure that fishery resource problems and opportunities are identified in a timely fashion and provides assistance to states, Indian tribes, and other federal agencies to address the problem or opportunity. Specific responsibilities of the Fisheries Activity are as follows:

1. to restore depleted, nationally significant fishery resources such as anadromous Pacific salmonids, Atlantic salmon, Great Lakes lake trout, striped bass, and other anadromous species of the Atlantic and Gulf coasts;
2. to mitigate for fishery resources impaired due to federal water-related development;
3. to assist with management of fishery resources on federal (primarily Service) and Indian tribal lands; and
4. to maintain a federal leadership role in scientifically based management of national fishery resources.

This list represents stewardship responsibilities that the Service shares with other nations, the states, Indian tribes, the private sector, and other federal agencies, for only through a strong cooperative effort will the Nation's freshwater, anadromous, and intercoastal fisheries be restored and maintained as wild, self-sustaining resources.

Organization

The current organization of the Service is shown in Fig. 1. Headed by the Director, the Service has eight Regional Directors, who provide line supervision to field operations, while five Assistant Directors provide staff support to the Director in their areas of expertise. The Office of the Assistant Director-Fisheries (Fig. 2) is divided into the Division of Fish Hatcheries, the Division of Management Assistance, the Office of Administration-Fisheries, the Office of Technical Fisheries Training, and the Recreational Fisheries Coordinator. Regions 1 through 7 of the Service (Fig. 3) are defined by geographical boundaries. Region 8 is the research operations branch of the Service. Actual implementation of fishery activities within the Service is carried out for the most part by regional and field office personnel. Each regional office has an Assistant Regional Director-Fisheries, who manages fisheries activities within a specific multistate region. At the field level, the Service maintains 75 fish hatcheries, 48 fishery assistance offices, 9 fish health centers, 4 fish technology centers, 6 fishery research centers, and various support facilities.

Operations

The functional components of the Service with clearly defined roles related to management of fisheries resources are as follows:

1. National Fish Hatchery System (NFHS). The NFHS is the oldest component of the Service's Fisheries Activity. The first federal fish hatchery was established in 1872 on the McCloud River at Baird, Calif. for the purpose of propagating salmon. At present the 75 fish hatcheries operated as part of the NFHS are responsible for producing and distributing fish and fish eggs required to mitigate impacts of federal water projects, restore significant species of inter-jurisdictional waters, stock waters under federal and state jurisdiction, and assist in the recovery of endangered fish species. During the past 10 years, the NFHS has produced in excess of 2.3 billion fish with a combined weight of 62 million pounds (Fig. 4). Production efforts of the NFHS focus on about 40 species or groups of species with commercial, sport, or Indian tribal ceremonial value, and on another 51 species that have been listed under the Endangered Species Act as either endangered or threatened. Fish eggs produced by the NFHS are used primarily to propagate fish at federal fish hatcheries or to stock directly into the wild. However, a significant number of eggs produced within the NFHS are traded for fish eggs of other species from various state fish hatcheries in a cooperative effort to produce fish eggs from the highest quality broodstock available and in the most economical manner. Fish health centers and fish technology centers, which are functional parts of the NFHS, provide expert technical assistance in fish health, fish nutrition, and fish culture to federal, state, Indian tribal, and private fish culturists. These centers also develop new and improved techniques for fishery resource management and fish culture.

   For Fiscal Year 1990 the NFHS will have $31.8 million available for operations and maintenance of facilities, with a Service staff of 519.

2. Lower Snake River Compensation Fund (LSRCF). From 1960 to 1975, four dams were constructed by the Federal Government on the Lower Snake River, a major tributary to the Columbia River. To mitigate for the loss of fall, spring, and summer chinook salmon and steel-head runs due to the four dams, the Federal Government directed the construction of 10 fish hatcheries and 12 associated substations (Fig. 5). The Service operates two of the hatcheries; the remaining eight are operated by the states under a cooperative agreement with the Service.

   For Fiscal Year 1990, the LSRCF will receive $7.9 million to operate and maintain facilities, with a Service staff of 14.

3. Fish and Wildlife Management Assistance (MA). The Service became involved with fishery assistance work in the early 1950's. Through a network of 48 assistance offices, MA develops and coordinates the implementation of plans for the management of freshwater, anadromous, and inter-coastal fisheries in cooperation with foreign governments, states, Indian tribes, private organizations, military, and other federal agencies.

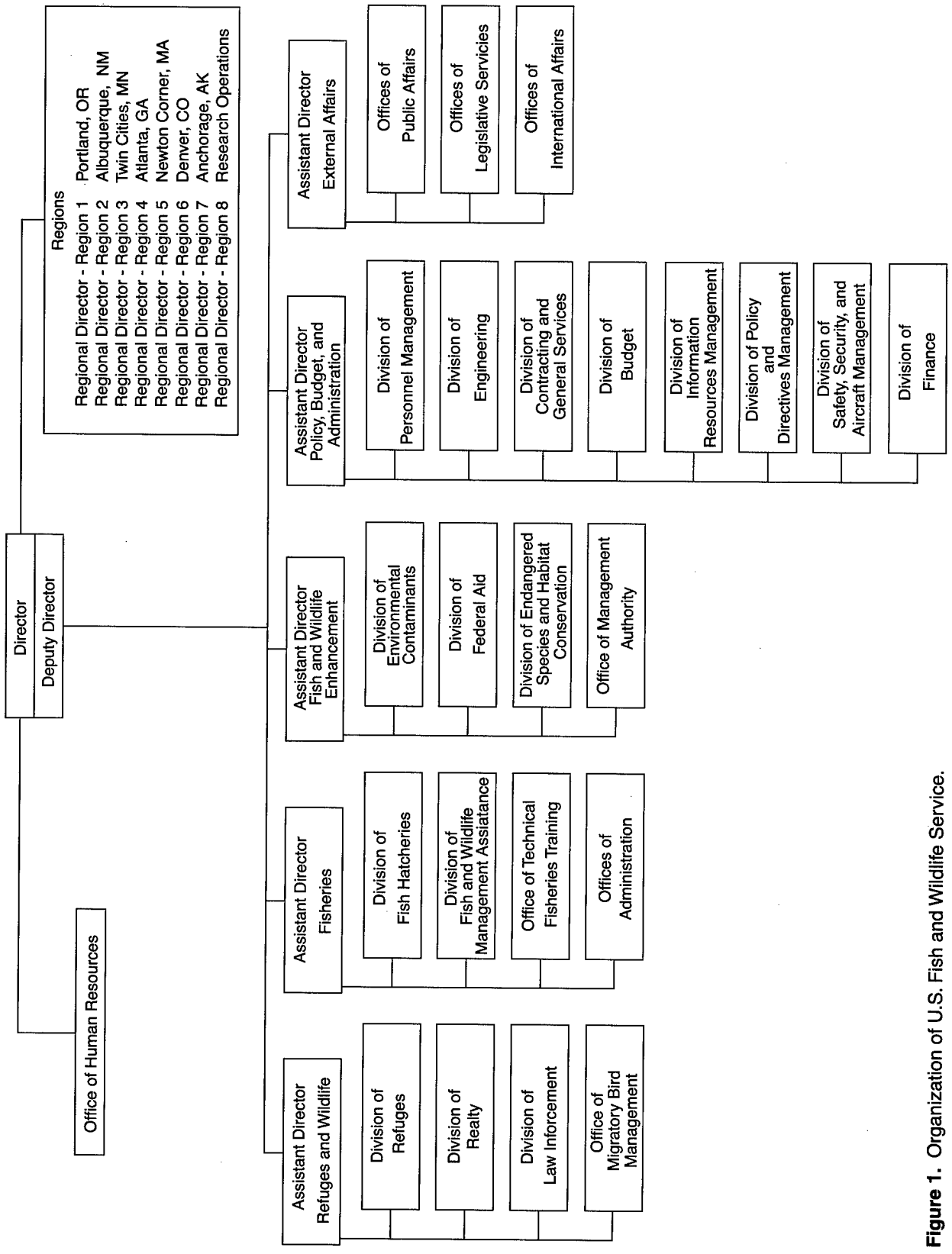


Figure 1. Organization of U.S. Fish and Wildlife Service.

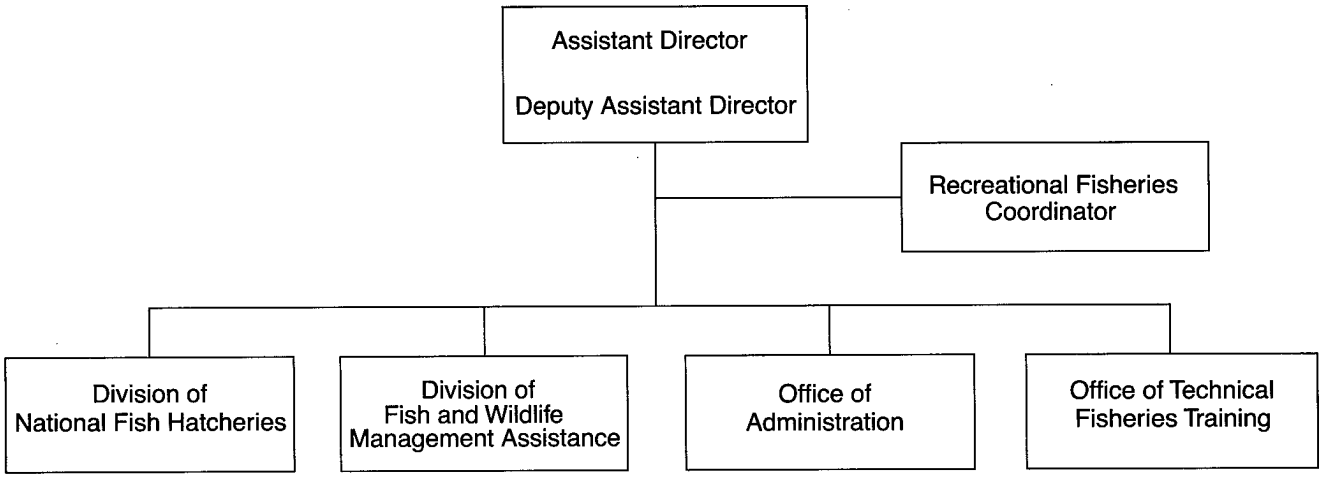


Figure 2. Organization of the Office of the Assistant Director-Fisheries

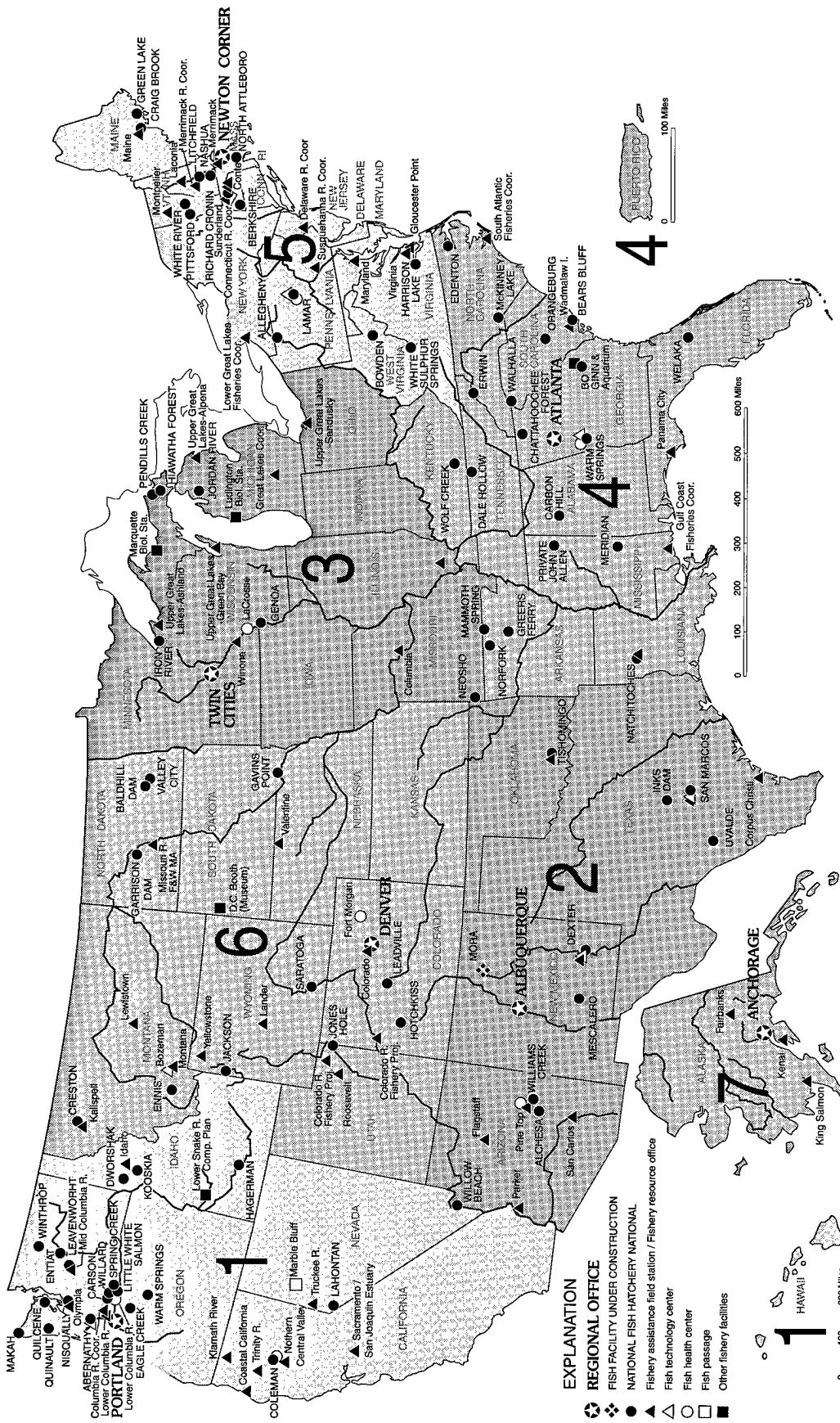


Figure 3. National fish hatcheries and fishery assistance stations.

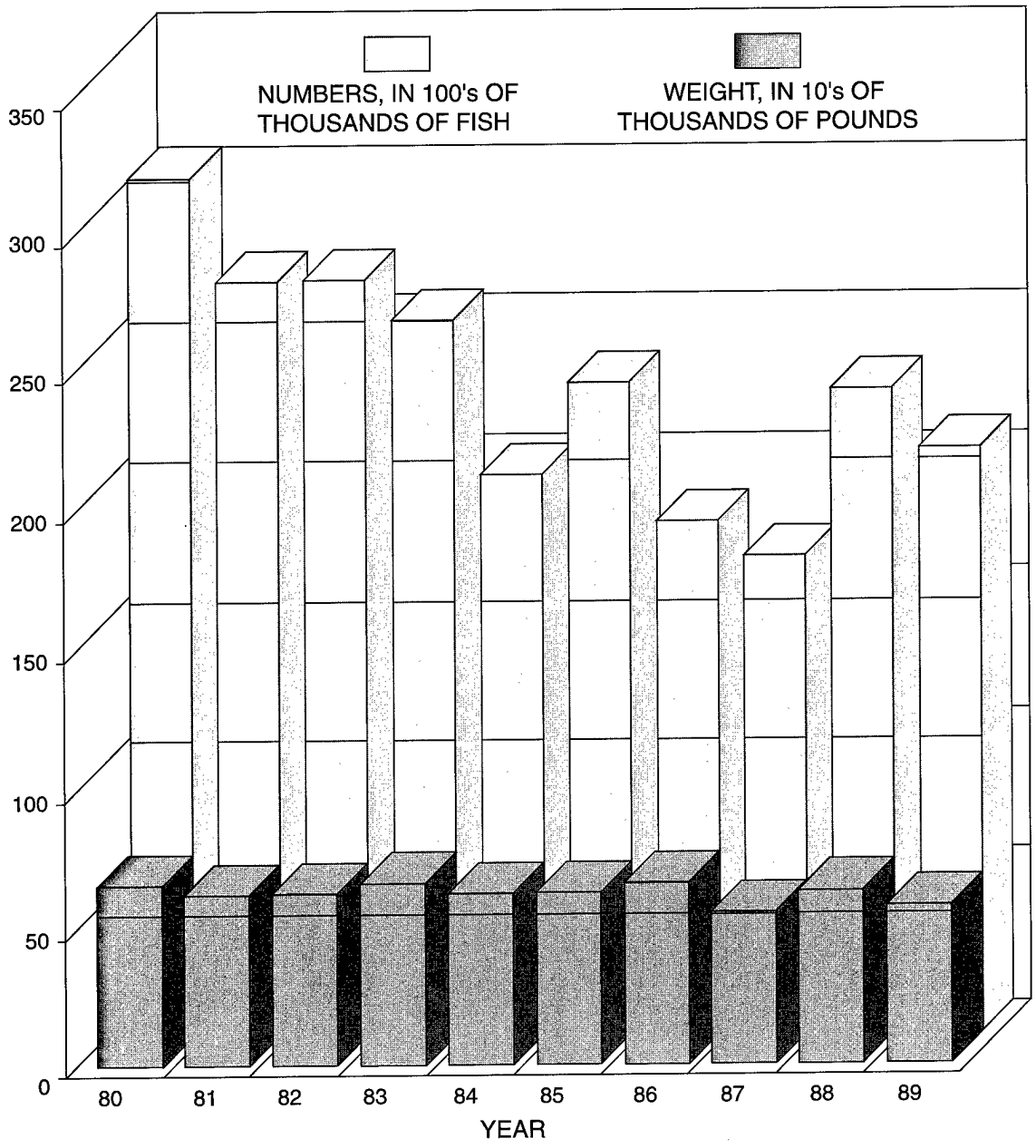
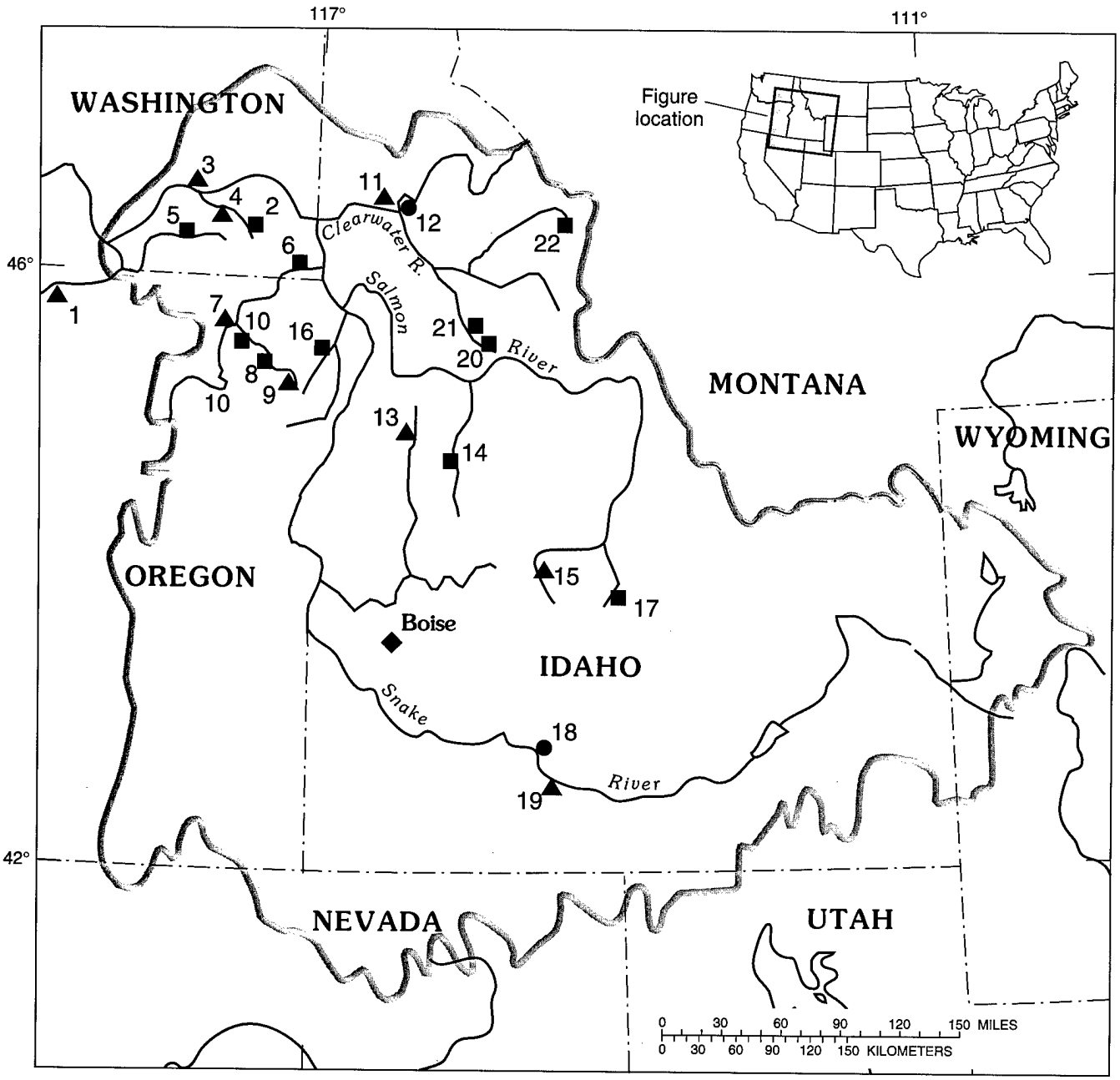


Figure 4. Ten years of fish distribution.



EXPLANATION

- Compensation Plan Boundary
- LSRCP coordination office
- National fish hatchery
- State fish hatecery
- Satellite fishery components

1. Irrigon
2. Curl Lake
3. Lyons Ferry
4. Tucannon River
5. Dayton Pond
6. Cottonwood Creek
7. Lookingglass
8. Big Canyon Creek
9. Wallowa
10. Little Sheep Creek
11. Clearwater Anadromous
12. Dworshak
13. McCall
14. South Fork Salmon
15. Sawtooth
16. Imnaha
17. East Fork Salmon
18. Hagerman
19. Magic Valley
20. Crooked River
21. Red River
22. Lochsa River

SEPTEMBER 1984

Figure 5. U.S. Fish and Wildlife Service Lower Snake River compensation plan facilities.

Current plans call for MA staff to prepare, update, or revise fishery management plans for 141 National Wildlife Refuges. Of the approximately 12 million acres of water nationwide in the National Wildlife Refuge System, about 2 million acres have significant fishery values and can provide sport fishing opportunities compatible with primary refuge purposes. Recreational fishing on refuges represents more than 13 million activity-hours each year. Technical information and assistance is provided by MA staff to other agencies, foreign nations, states, and Indian tribes on the conservation and management of fishery resources. Management Assistance staff also oversees the distribution of funds for the Service's portion of the Anadromous Fish Grants Program. The Service will distribute $1.5 million in Fiscal Year 1990 for conserving and enhancing anadromous fish stocks outside the Columbia River basin.

For Fiscal Year 1990, MA will have an operating budget of $7.8 million with a Service staff of 123.

4. Fisheries Research. Region 8 of the Service operates six National Fisheries Research Centers, which conduct comprehensive research and development activities in the areas of fish health, environmental contaminants, registration of drugs and chemicals for fisheries use, nutrition, fish exotic to the United States, physiology, ecology, and genetics. Work carried out at these centers enables the Service to keep abreast of changing problems in fisheries management through the development of appropriate and timely methodology. Another significant function of Research is the international dissemination of this technical fisheries information.

   The operating budget for Research for fisheries activities in Fiscal Year 1990 is $16.2 million, with a Service staff of 308.

5. Federal Aid in Sports Fisheries Restoration Act. The Federal Aid in Sport Fish Restoration Act of 1950, commonly referred to as the Dingell-Johnson Act, authorized a permanent program of federal financial assistance to the states for the restoration and management of marine and freshwater sport fish of the United States. Program funds were derived from a 10% excise tax on fishing equipment. In 1984, the act was amended (Wallop-Breaux Amendment) to add revenues from an excise tax on imported fishing tackle, pleasure boats and yachts, and a tax on fuels used to power motorboats to the existing funding base. The amendment also made provisions for states to provide boating access and aquatic resources education to the public. States are reimbursed through the Federal Aid program for up to 75% of the cost of implementing fisheries projects that meet broad federal statutory guidelines and requirements. This program is very popular because the sportsman that pays the excise tax that funds the program benefits directly from the projects conducted through the program (user pays—user benefits).

   For Fiscal Year 1990, $179 million will be available to states to conduct fishery related projects through the Federal Aid program.

Success Stories

The Service has played a vital role in the successful restoration and mitigation of many depleted fish populations nationwide, as demonstrated by the following examples.

Striped Bass (*Morone saxatilis*)

Historically, striped bass were one of America's most important recreational and commercial fisheries; millions of pounds were landed each year. However, by the mid to late 1970's, there was a significant decline in the landings of striped bass, and the need to better manage the resource became obvious. The restoration of striped bass in Atlantic and Gulf Coast waters is one of the Service's highest priorities. The Service will spend $5 million on striped bass restoration efforts in Fiscal Year 1990. During the past 10 years, Service hatcheries in the Southeast, Southwest, and mid-Atlantic states, working in cooperation with state fish and wildlife agencies and Service fisheries management activities, have distributed nearly 40 million striped bass of various sizes into the streams and tributaries along the Atlantic and Gulf coasts (Fig. 6).

Today striped bass numbers are rebounding. Chesapeake Bay was once credited with hatching 90% of all striped bass found in the Atlantic Ocean. After 10 years of very low levels of striped bass production in Chesapeake Bay, initial information from the 1989

Maryland young-of-the-year index for Chesapeake Bay striped bass indicates that striped bass numbers in the Bay are increasing significantly. As a result of the Maryland index, some states plan to reopen their striped bass fishery to limited sport commercial harvest in 1990.

Great Lakes Lake Trout (*Salvelinus namaycush*)

The Great Lakes provided a large and successful commercial fishery in the early 1900's, composed primarily of lake trout, whitefish, and lake herring. The combined effects of an unregulated fishery, habitat destruction, water pollution, and the invasion of the parasitic sea lamprey eliminated lake trout in Lakes Erie, Ontario, and Michigan, with only vestigial populations remaining in Lakes Superior and Huron by the early 1950's. In 1954, the United States and Canada signed a treaty forming the Great Lakes Fishery Commission for the purpose of overseeing the restoration of commercial and sport fish in the Great Lakes. Part of the annual funding provided by the Commission (United States share is $45 million) for Fiscal Year 1990) has been used by Service hatcheries to produce and distribute lake trout in the Great Lakes. Nearly 67 million lake trout of various sizes with a combined weight in excess of 3 million pounds have been stocked in the Great Lakes by the Service during the last 10 years (Fig. 7).

Service efforts to reduce parasitic sea lamprey population levels in the Great Lakes, along with the distribution of hatchery-reared lake trout, have resulted in progress toward restoring lake trout in all lakes. In Lake Ontario, survival of adult lake trout exceeded 65% for the first time on record in 1987. The eastern end of Lake Superior has been essentially rehabilitated with a healthy population of adult lake trout. Lake Huron is showing increasing signs of natural reproduction, with more unmarked lake trout being recovered each year. Natural reproduction in Lake Michigan has produced fry, but unmarked (nonhatchery) fingerlings have yet to be found.

Current Issues

National Recreational Fisheries Policy

The interest of the American public in sport fishing continues to increase at a significant rate. Increased interest in fishing and an increase in leisure time available to Americans translates directly to more recreational anglers. Today, fish provide sport to over 60 million people in the United States. These anglers spend 1 billion days fishing each year and directly contribute $30 billion to the national economy. Experts predict that by the year 2030, recreational fishing effort in the United States will increase by 40%.

The Service recognized the importance of recreational fisheries on a national scale and took the lead in developing a National Recreational Fisheries Policy in June of 1988. The policy details the benefits to the Nation of the multiple uses of fisheries resources. However, as a recreational fisheries policy, it focuses on the specific issues and significant social and economic benefits related to recreational fisheries.

The policy is an umbrella document that provides long-term common goals for conserving and enhancing the Nation's recreational fisheries. The policy suggests these goals may best be attained through a process of government to private sector cooperation and coordination consistent with existing authorities and responsibilities. The Service, along with other state, federal, Indian tribal, and private cooperators is currently developing specific plans to implement the policy.

Aquaculture

Private aquaculture, public aquaculture, and public fishery management are interrelated in a variety of ways. These interrelationships, past, present, and future, make service to private sector aquaculture a public interest and a responsibility of the Service. The Service provides valuable assistance to aquaculturists based on practical experience gained from operating fish hatcheries for over 100 years, along with expertise amassed from research and development activities. At present, the aquaculture industry of the United States produces over 800million pounds of fish and aquatic

animals annually, with a total economic value of $8 billion. The aquaculture industry is also directly responsible for the employment of a large number of people across the Nation. With this strong growth of the aquaculture industry in the United States, demand continues to increase significantly for a wide range of information and services. The Service, through a national network of aquaculture coordinators, fish health centers, fish technology centers, fish research centers, and training facilities has recommitted to providing private and public sector aquaculturists with information and services within the following areas:

fish feeds, feeding, and nutrition

- fish health
- drug and chemical registration
- water quality; aeration studies and effluent control
- genetics and reproductive physiology
- hatchery design and operations
- cultural techniques
- contaminant problems; off flavor, pesticides, and heavy metals.

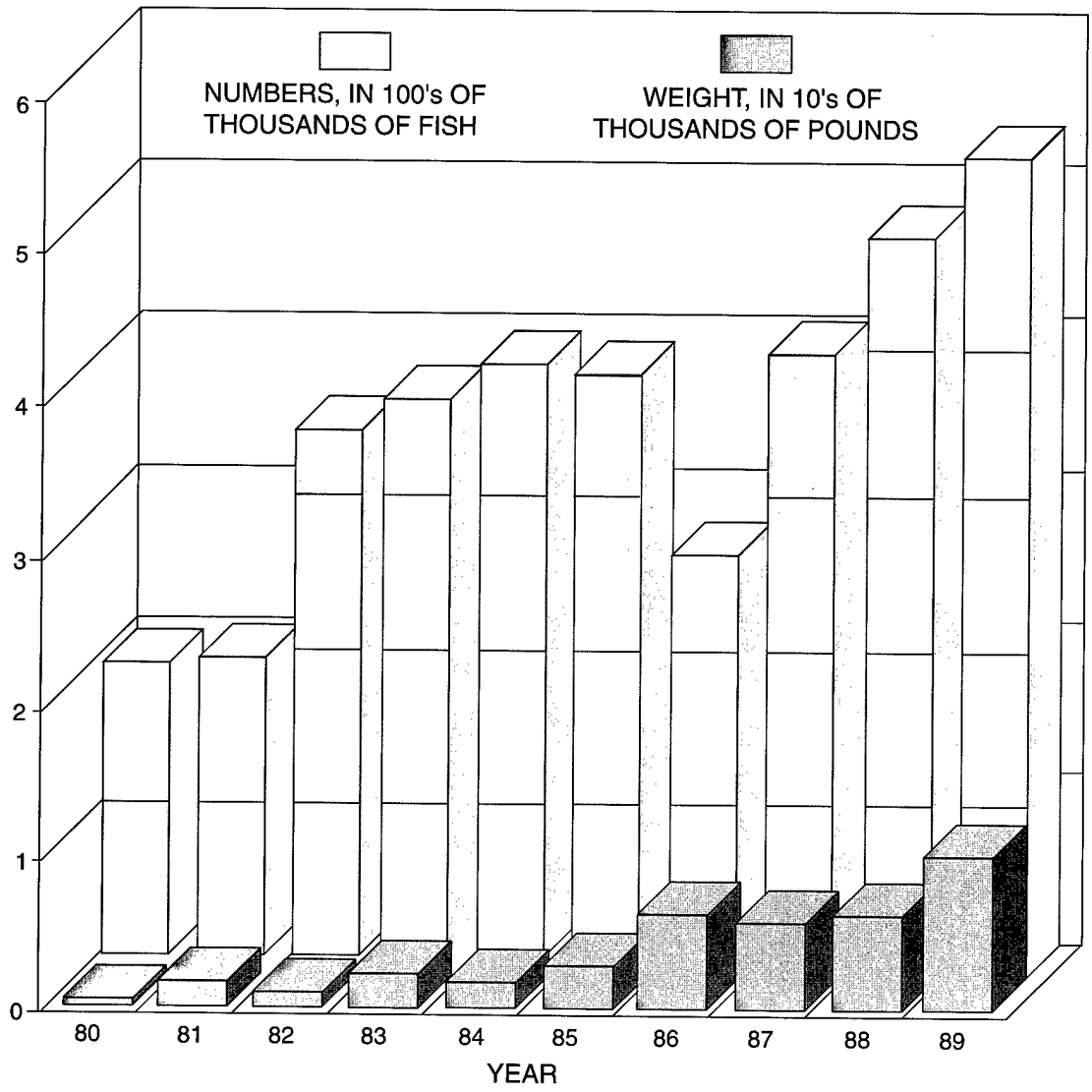


Figure 6. Ten years of fish distribution for striped bass.

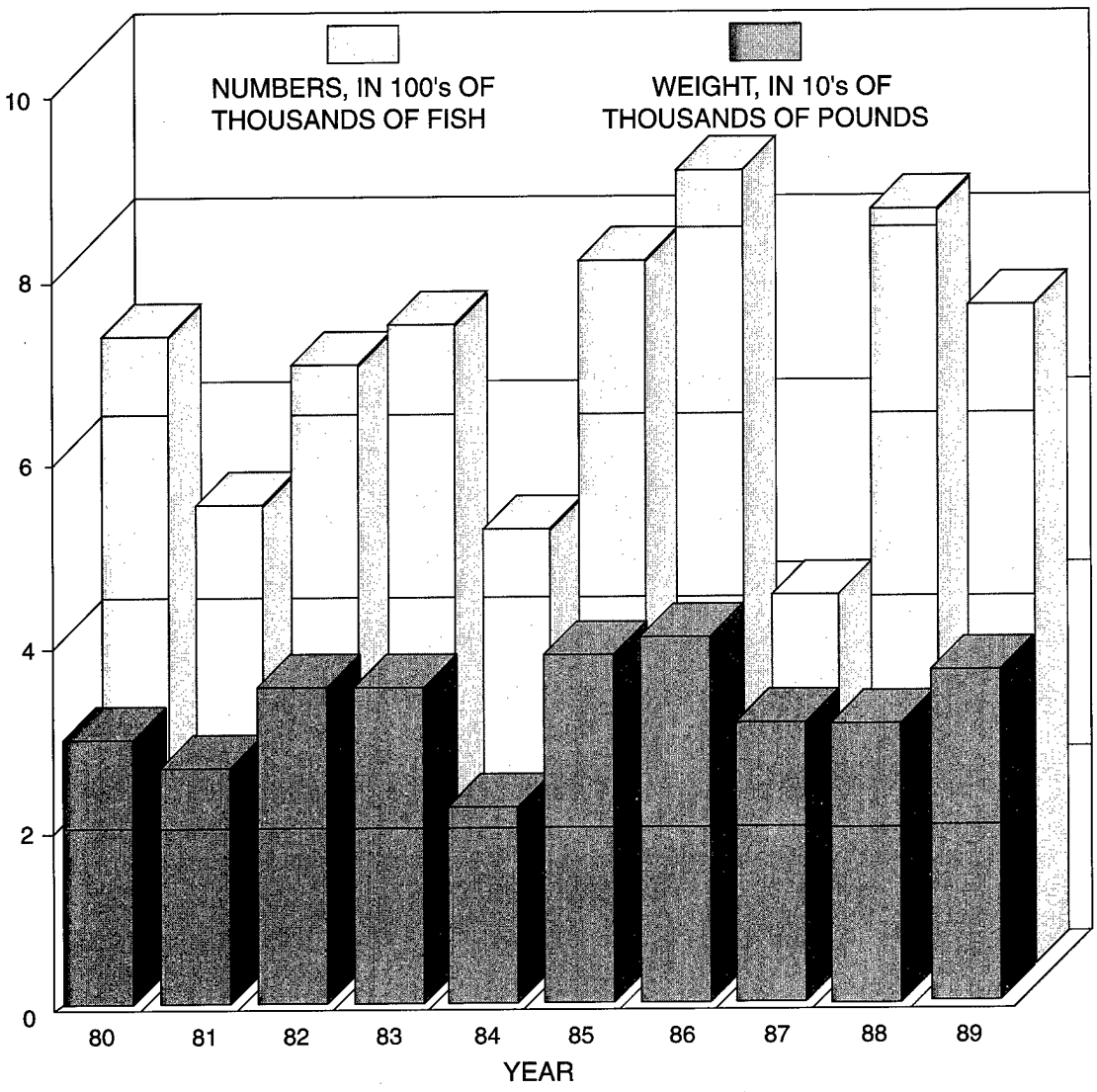


Figure 7. Ten years of fish distribution for lake trout in the Great Lakes.

Appendix—Speakers and Guests

USSR Delegation

S.A. Studenetskiy, USSR Head of Delegation, All Union Research Institute of Marine Fisheries and Oceanography (VNIRO), Moscow, Russia.

O.F. Gritsenko, VNIRO, Moscow, Russia.

I.A. Burtsev, VNIRO, Moscow, Russia.

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V.L. Karpenko, TINRO, Kamchatka Peninsula.

A.F. Grishin, Fisheries Directorate, Sakhalin Island.

M. Ya. Kazarnovskiy, VNIRO, Moscow.

A.I. Ryazheskikh, VNIRO, Moscow.

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USA Delegation--Continued

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